

तमसो मा ज्योतिर्गमय

VISVA BHARATI
LIBRARY
SANTINIKETAN

506

P.N.I.S.I

v.16, 1950

189287

PROCEEDINGS
OF THE
NATIONAL INSTITUTE OF SCIENCES OF INDIA

VOL. XVI
1950

NATIONAL INSTITUTE OF SCIENCES OF INDIA
DELHI

INDEX
VOL. XVI
1950

INDEX

	Page		Page
Adaptive modifications in a hill-stream catfish, <i>Glyptothorax telchitta</i> (Hamilton) (Bhatia) ..	271	Annual General Meeting, Fifteenth. Proceedings ..	311
Adsorption of gases by industrially important catalysis and kinetics of gas reaction. (Research report) (VedaRaman)	360	Annual Report, 1949 ..	315
Affinity of dyes for cellulose and proteins. (Research report) (Tilak) ..	351	Anti-thiamine factor in freshwater mussel <i>Lamellidens marginalis</i> . <i>In vivo</i> studies (Reddi) ..	221
Agarwala, B. K.—see Auluck, F. C., Singwi, K. S. and Agarwala, B. K.		Artificial culture of embryo and study of factors influencing the successful growth of embryo in synthetic media under tropical conditions (Research report) (Mitra) ..	368
Agrawal, J. S.—The embryo sac of <i>Fritillaria liliacea</i> ..	87	Atmospheric processes (Venkiteshwaran) ..	19
Agronomy and land utilization (Kalamkar) ..	495	Auden, J. B.—Cement and multi-purpose projects ..	545
Ahmed, Rais—The nonlinear method of circuit analysis ..	255	Auden, J. B.—Some factors concerning the transport of sediment by rivers ..	501
Algebraic difference equations. Real continuous solutions (Shah)	11	Auden, J. B.—The rôle of geology in multi-purpose projects ..	431
Algology (Research report) (Singh) ..	371	Auluck, F. C.—Statistical thermodynamics and quantum electrodynamics. (Research report)	350
Alikunhi, K. H.—see Ganapati, S. V. and Alikunhi, K. H.		Auluck, F. C., Singwi, K. S. and Agarwala, B. K.—On a new type of partition ..	147
Alkali halides. Luminescence spectra (Bose and Sharma) ..	47	Band spectrum of zinc bromide (Ramasastry and Sreeramamurty) ..	305
Alkaline phosphatase in the uropygial gland of normal and of androgen treated pigeons. Studies on cytochemistry of hormone action (Kar) ..	41	Banerji, S. K.—Problems of river forecasting in India ..	397
Alkaline phosphatase in the ovary of normal and of androgen treated pigeons. Distribution and concentration. Studies on cytochemistry of hormone action (Kar) ..	43	Basu, J. K. and Puranik, N. B.—A pattern of land-use planning in the dry areas of the Bombay State ..	481
Alkaline phosphatase in the genital system of female pigeons. The effect of progesterone and desoxycorticosterone acetate on the distribution and concentration. Studies in cytochemistry of hormone action (Kar) ..	177	Basu, S. P.—Ecology of sewage-irrigated fisheries in the Bidyadhari spill area, with particular reference to the bionomics of carps cultured therein (Research report) ..	366

	Page		Page
Bats. Studies on reproduction in bats. Research report (Ramakrishna Iyer) ..	360	Chandersekhara, B. S.—see Saha, N. K., Chandersekhara, B. S. and Sundaresan, M. K.	
Behari, R. and Mishra, R. S.—Bianchi's characteristic function in a congruence of Ribaucour ..	83	Changes in pH of the white and yolk of fertilized hen's egg during incubation in air, carbon dioxide and liquid paraffin (Subba Rao, Wajid and Sanjiva Rao) ..	5
Bhatia, Bimla—Adaptive modifications in a hill-stream catfish, <i>Glyptothorax telchitta</i> (Hamilton) ..	271	Circuit analysis. The nonlinear method (Ahmed) ..	255
Bhattacharya, P. C.—Study of mesotron and the allied problems (Research report) ..	369	Coelomoducts and nephridia of serpulimorpha and cirratulidae (Krishnan) ..	29
Bhimasenachar, J.—Elastic constants of corundum ..	241	Colchicine. Its effect on rice (Ghosh) ..	135
Bhimasenachar, J.—Elastic properties of polycrystals. (Research report) ..	350	Colloids. (Research report) (Subba Rao) ..	352
Bhimasenachar, J. and Seshagiri Rao, T.—Elastic constants of some cubic nitrates ..	235	Combined vacuum furnace and mass spectrometer for universal use. Its construction (Srivastava and Saharia) ..	263
Bianchi's characteristic function in a congruence of Ribaucour (Behari and Mishra) ..	83	Complexes formed by sodium hexametaphosphate with strontium, barium and lead ions by conductivity data. Studies in hexametaphosphates, Part II (Mehrotra and Dhar) ..	67
Bose, H. N.—Luminescence spectra of different types of phosphors under X-rays and cathode rays, specially at low temperatures (Research report) ..	365	Compressible fluid flow. (Research report) (Thiruvengkatachar) ..	357
Bose, H. N. and Sharma, J.—Luminescence spectra of alkali halides ..	47	Congruence of Ribaucour. Bianchi's characteristic function (Behari and Mishra) ..	83
Bose, N. K.—Hydrology ..	421	Construction of a combined vacuum furnace and mass spectrometer for universal use (Srivastava and Saharia) ..	263
Bose, S. N.—Presidential Address, Fifteenth Annual General Meeting, 2-1-1950 ..	312	Corundum. Elastic constants of corundum (Bhimasenachar) ..	241
Breeding habits, eggs and early life history of the Indian shad, <i>Hilsa Ilisha</i> (Ham.) in the Nabada river (Kulkarni) ..	169	Cubic Nitrates. Elastic constants of some cubic nitrates (Bhimasenachar and Rao) ..	235
Burman, U. R.—Internal constitution of stars (Research report) ..	353	Cytochemistry of hormone action. Studies (Kar) ..	41, 43, 177
Carbon dioxide and liquid paraffin as preservatives for egg ..	8	Cytogenetics of yeast (Research report) (Subramaniam) ..	373
Cement and multi-purpose projects (Auden) ..	545	Cytological investigation of the mango, <i>Mangifera indica</i> L., and the allied Indian species (Mukherjee) ..	287

	Page		Page
Cytology of helobiales. (Research report) (Sunder Rao) ..	356	Elastic constants of corundum (Bhimasenachar) ..	241
Damodar Valley, Rehabilitation. (Raman) ..	565	Elastic constants of solids. Determination by pulse method (Krishnaji) ..	227
Das-Gupta, B. C.—Malaria and its control ..	555	Elastic constants of some cubic nitrates (Bhimasenachar and Rao) ..	235
Das Gupta, K.—Soft X-ray spectroscopic study of solids (Research report) ..	354	Elastic properties of polycrystals. (Research report) (Bhimasenachar) ..	350
Datta, P. C.—Synthesis of the alicyclic systems related to the steroids. Synthesis of sesquiterpenes and the acids isolated from degeneration of these bodies (Research report) ..	370	Embryo sac of <i>Fritillaria liliacea</i> (Agrawal) ..	87
Derived Fourier series. Nörlund summability (Prasad and Siddiqi) ..	71	Embryological study of <i>Lerenhukia dubia</i> sord. in lehm (Subramanyam) ..	245
Desert locust with special reference to its musculature. Study of phases. (Research report) (Misra) ..	355	Embryology of microchiroptera. Part VI. Structure of the placenta in the Indian vampire bat, <i>Lyroderma lyra lyra</i> (Geoffroy) (Megadermatidae) (Gopalakrishna) ..	93
Design (Rao) ..	443	Factory effluents from the Mettur Chemical and Industrial Corporation, Ltd., Mettur Dam, Madras, and their pollutional effects on the fisheries of the river Cauvery (Ganapati and Alikunhi) ..	189
Desikachary, T. V.—Morphology and taxonomy of some South Indian algae (Research report) ..	367	Fellows, Honorary ..	332
Determination of elastic constants of solids of pulse method (Krishnaji) ..	227	Fellows Ordinary ..	325
Developmental studies. A comparative account of the origin, development and morphology of the stipules of <i>Artocarpus integrifolia</i> L., <i>Ficus religiosa</i> L. and <i>Ficus elastica</i> Roxb. (Mitra) ..	157	Fisheries conservation and development (Hora) ..	521
Dhar, N. R.—see Mehrotra, R. C. and Dhar, N. R.		Fisheries of the Cauvery. Pollutional effects caused by factory effluents from the Mettur Chemical and Industrial Corporation, Ltd., Mettur Dam, Madras (Ganapati and Alikunhi) ..	189
<i>Dicroidium</i> (<i>thinnfeldia</i>) fronds from the mesozoic of Australia. A preliminary account of the structure of the cuticles (Jacob and Mrs. C. Jacob) ..	101	Fishing industry. Its growth. Sidelights on fifteen years' work. First Chandra Kala Hora Memorial Lecture (Setna) ..	207
Dutt, A. B.—Sand-stowing ..	513	Flood control (Majumdar) ..	463
Ecology of sewage-irrigated fisheries in the Bidyadhari spill area, with particular reference to the bionomics of carps cultured therein (Research subject) (Bose) ..	366	Fossil plants with reference to their structure and affinities in relation to question of plant evolution and palaeography (Research report) (Sitholey) ..	372

	Page		Page
Freshwater mussel, <i>Lamellidens marginalis</i> . <i>In vivo</i> studies on the 'anti-thiamine factor' (Reḡḡdi)	221	Hen's egg. Changes in pH of the white and yolk of fertilized hen's egg (Rao, Wajid and Rao) ..	5
<i>Fritillaria biliacea</i> . The embryo sac (Agrawal)	87	Hexametaphosphates. Studies. (Mebrotra and Dhar) ..	59, 67
<i>Fusaria</i> from Indian soils, with special reference to physiological races (Research report) (Subramanian)	369	Hill-stream catfish, <i>Glyptothorax telchitta</i> Hamilton. Its adaptive modifications (Bhatia) ..	271
Ganapati, S. V. and Alikunhi, K. H.—Factory effluents from the Mettur Chemical and Industrial Corporation, Ltd., Mettur Dam, Madras, and their pollutional effects on the fisheries of the river Cauvery	189	<i>Hilsa Hisha</i> (Ham.) Indian shad, in the Nerbada river. Its breeding habits, eggs and early life history (Kulkarni) ..	169
Ghosh, B. N.—Physiological studies on the effect of colchicine on rice	135	Hora (Chandra Kala) Memorial first lecture (Setna) ..	207
<i>Glyptothorax telchitta</i> Hamilton. Hill-stream catfish. Its adaptive modifications (Bhatia) ..	271	Hora, S. L.—Fisheries conservation and development ..	521
<i>Gobioplerus chuno</i> (Hamilton), the Indian transparent goby. Its larval development with observations on bionomics (Pillay and Sarojini) ..	181	Hormone action. Studies on cytochemistry (Kar) ..	41, 43, 177
Gopalakrishna, A.—Studies on the embryology of microchiroptera. Part VI. Structure of the placenta in the Indian vampire bat, <i>Lyroderma lyra lyra</i> (Geoffroy) (Megadermatidae)	93	Hydrology (Bose)	421
Growth of the fishing industry. Sidelights on fifteen years' work. First Chandra Kala Memorial Lecture (Setna) ..	207	Hysteresis in sorption XVII. Hardening of sericin and its influence on sorption-desorption Hysteresis (Rao, Rao, Vasudevamurthy and Rao) ..	1
Guha, B. C.—Introductory speech at the symposium on multi-purpose river projects in India's national economy ..	379	Incubation of hen's egg in air, carbon dioxide and liquid paraffin (Rao, Wajid and Rao) ..	5
Hardening of sericin and its influence on sorption-desorption hysteresis. Hysteresis in sorption XVII. (Subba Rao, M. B. Rao, Vasudevamurthy and Sanjiva Rao) ..	1	Indian shad, <i>Hilsa Hisha</i> (Ham.) in the Nerbada river. Breeding habits, eggs and early life history (Kulkarni) ..	169
		Indian transparent goby, <i>Gobioplerus chuno</i> (Hamilton). Its larval development with observations on bionomics (Pillay and Sarojini) ..	181
		Indian vampire bat, <i>Lyroderma lyra lyra</i> (Geoffroy). Structure of its placenta (Gopalakrishna) ..	93
		Irrigation (Singh)	475
		Jacob, K. and Jacob (Mrs.) C.—A preliminary account of the structure of the cuticles of <i>Dicroidium thinnfeldia</i> fronds from the mesozoic of Australia ..	101
		Jacob, (Mrs.) Chinna—see Jacob, K. and Jacob (Mrs.) C.	

	Page
Kalamkar, R. J.—Agronomy and land utilization	495
Kar, Amiya B.—Studies on cytochemistry of hormone action	41, 43, 177
Khedkar, V. R.—Mineral utilization	541
Krishnaji—Determination of elastic constants of solids by pulse method	227
Krishnan, G.—On the nephridia and coelomoducts of serpulimorpha and cirratulidae ..	29
Kulkarni, C. V.—Breeding habits, eggs and early life history of the Indian shad, <i>Hilsa Hilsa</i> (Ham.) in the Narbada river ..	169
<i>Lamellidens marginalis</i> , fresh-water mussel. <i>In vivo</i> studies on the anti-thiamine factor (Reddi)	221
Land utilization and agronomy (Kalamkar)	495
Land-use planning in the dry areas of the Bombay State. A pattern (Basu and Puranik) ..	481
Larval development of the Indian transparent goby, <i>Gobioplerus chano</i> (Hamilton), with observations on its bionomics (Pillay and Sarojini)	181
<i>Lerenhukia dubia</i> sond. in lehm. An embryological study (Subramanyam)	245
Luminescence spectra of alkali halides (Bose and Sharma) ..	47
Luminescence spectra of different types of phosphors under X-rays and cathode rays, specially at low temperatures (Research report) (Bose)	365
<i>Lyproderma lyra lyra</i> (Geoffroy), the Indian vampire bat. Structure of the placenta (Gopalakrishna)	93
Majumdar, K. N.—On numbers which can be expressed by a given form	99
Majumdar, S. C.—Flood control	463

	Page
Malaria and its control (Das-Gupta)	555
Mango. Cytological investigation of the mango <i>Mangifera indica</i> L., and the allied Indian species (Mukherjee)	287
Mehrotra, R. C. and Dhar, N. R.—Studies in hexametaphosphates	59, 67
Menon, K. P. P.—Power development	529
Mesotron and the allied problems (Research report) (Bhattacharya)	369
Mettur Chemical and Industrial Corporation, Ltd., Mettur Dam, Madras. The factory effluents and their pollutional effects on the fisheries of the river Cauvery (Ganapati and Alikunhi)	189
Microchiroptera. Studies on embryology (Gopalakrishna) ..	93
Mineral utilization (Khedkar) ..	541
Mineral utilization (West) ..	537
Mishra, R. S.—see Behari, R. and Mishra, R. S.	
Misra, S. D.—Study of phases of desert locust with special reference to its musculature (Research report)	355
Mitra, G. C.—Developmental studies. A comparative account of the origin, development and morphology of the stipules of <i>Artocarpus integrifolia</i> L., <i>Ficus religiosa</i> L. and <i>Ficus elastica</i> Roxb.	157
Mitra, Jyotirmay—Artificial culture of embryo and study of factors influencing the successful growth of embryo in synthetic media under tropical conditions (Research report) ..	368
Morphology and taxonomy of some South Indian algae (Research report) (Desikachary)	367
Morphology of the stipules of <i>Artocarpus integrifolia</i> L., <i>Ficus religiosa</i> L. and <i>Ficus elastica</i> Roxb. (Mitra)	157

	Page		Page
Mukherji, P. C.—Synthesis of steroid sex-hormones and hormones of adrenal cortex (Research report) ..	364	Soil conservation engineering (Vajda) ..	489
Mukherjee, S. K.—Cytological investigation of the mango, <i>Mangifera indica</i> L. and the allied Indian species ..	287	Some factors concerning the transport of sediment by rivers (Auden) ..	501
Multi-purpose projects and cement (Auden) ..	545	Mussel (freshwater), <i>Lamellidens marginalis</i> . <i>In vivo</i> studies on the anti-thiamine factor (Reddi) ..	221
Multi-purpose projects. Rôle of geology (Auden) ..	431	Navigation (Singh) ..	469
Multi-purpose river projects in India's national economy. Papers contributed to the Symposium held on 4th and 5th August, 1950: ..	375	Nephridia and coelomoducts of serpulimorpha and cirratulidae (Krishnan) ..	29
Agronomy and land utilization (Kalamkar) ..	495	Nonlinear method of circuit analysis (Ahmed) ..	255
Cement and multi-purpose river projects (Auden) ..	545	Nörlund summability of derived Fourier series (Prasad and Siddiqi) ..	71
Design (Rao) ..	443	Numbers which can be expressed by a given form (Majumdar) ..	99
Economic significance of the multi-purpose approach (Mazumdar) ..	571	Origin, development and morphology of the stipules of <i>Artocarpus integrifolia</i> L., <i>Ficus religiosa</i> L. and <i>Ficus elastica</i> Roxb. (Mitra) ..	157
Fisheries conservation and development (Hora) ..	521	Partition. A new type (Auluck, Singwi and Agarwala) ..	147
Flood control (Majumdar) ..	463	Patel, Vallabhbhai—An extract of his address to the Central Board of Irrigation, New Delhi, on 24-10-50 ..	577
Hydrology (Bose) ..	421	Pattern of land-use planning in the dry areas of the Bombay State (Basu and Puranik) ..	481
Introductory speech (Guha) ..	377	Physiological studies on the effect of colechicine on rice (Ghosh) ..	135
Irrigation (Singh) ..	475	Pillay, T. V. R. and Sarojini, K. K.—On the larval development of the Indian transparent goby, <i>Gobiopertus chuno</i> (Hamilton) with observations on its bionomics ..	181
Malaria and its control (Das-Gupta) ..	555	Placenta in the Indian vampire bat. Structure (Gopalakrishna) ..	93
Mineral utilization (Khedkar) ..	541	Planning. Principles (Sain) ..	381
Mineral utilization (West) ..	537	Power development (Menon) ..	529
Navigation (Singh) ..	469		
Pattern of land-use planning in the dry areas of the Bombay State (Basu and Puranik) ..	481		
Power development (Menon) ..	529		
Principles of planning (Sain) ..	381		
Problems of river forecasting in India (Banerji) ..	395		
Rehabilitation in the Damodar Valley (Raman) ..	565		
Rôle of geology in multi-purpose projects (Auden) ..	431		
Sand-stowing (Dutt) ..	513		

	Page		Page
Prasad, B. N. and Siddiqi, J. A.— On the Nörlund summability of derived Fourier series ..	71	River valley projects. Co- ordination (Sain) ..	393
Preparation and properties of sodium hexametaphosphate and a study of the extent of complex formation with calcium ions by conductivity data. Studies in hexameta- phosphates (Mehrotra and Dhar) ..	59	Rôle of geology in multi-purpose projects (Auden) ..	431
Presidential Address, Fifteenth Annual General Meeting, on 2-1-50. (Bose) (Summary) ..	312	Saha, N. K., Chandrasekhara, B. S. and Sundaresan, M. K.— A simple form of voltage stabilizer ..	127
Principles of planning (Sain) ..	381	Saharia, V. N.—see Srivastava, B. N. and Saharia, V. N.	
Problems of river forecasting in India (Banerji) ..	397	Sain, Kanwar—Principles of planning ..	381
Pulse method. Determination of elastic constants by pulse method (Krishnaji) ..	227	Sand-stowing (Dutt) ..	513
Puranik, N. B.—see Basu, J. K. and Puranik, N. B.		Sanjiva Rao, B.—see Subba Rao, K., Rao, M. B., Vasudeva- murthy, A. R. and Sanjiva Rao, B.	
Ramakrishna Iyer, P. A.—Studies on reproduction in bats (Research report) ..	360	Sanjiva Rao, B.—see Subba Rao, K., Wajid, M. A. and Sanjiva Rao, B.	
Raman, K. S. V.—Rehabilitation in the Damodar Valley ..	565	Sarkar, N. K.—Studies in certain aspects of the chemistry and physiology of snake-bite (Research report) ..	362
Rao, K. L.—Design ..	443	Sarojini, K. K.—see Pillay, T. V. R. and Sarojini, K. K.	
Rao, M. B.—see Subba Rao, K., Rao, M. B., Vasudevamurthy, A. R. and Sanjiva Rao, B.		Serpulimorpha and cirratulidae. The nephridia and coelo- ducts (Krishnan) ..	29
Ramasastri, C. and Sreerama- murthy, K.—Band spectrum of zinc bromide ..	305	Seshagiri Rao, T.—see Bhima- senachar, J. and Seshagiri Rao.	
Real continuous solutions of algebraic difference equations (Shah) ..	11	Setna, S. B.—First Chandra Kala Hora Memorial Lecture. Growth of the fishing industry. Sidelights on fifteen years' work ..	207
Reddi, K. K.— <i>In vivo</i> studies on the anti-thiamine factor in freshwater mussel (<i>Lamellidens marginalis</i>) ..	221	Shah, S. M.—On real continuous solutions of algebraic difference equations ..	11
Rehabilitation in the Damodar valley (Raman) ..	565	Sharma, J.—see Bose, H. N. and Sharma, J.	
Research Fellows Research reports ..	350	Siddiqi, J. A.—see Prasad, B. N. and Siddiqi, J. A.	
Research Fellowships, I.C.I. ..	322	Singh, Man—Irrigation ..	475
Research Fellowships, N.I.S.I. ..	321	Singh, Man—Navigation ..	469
River forecasting in India. Problems (Banerji) ..	397	Singh, R. N.—Algology (Research report) ..	371

	Page		Page
Singwi, K. S.—see Auluck, F. C., Singwi, K. S. and Agarwala, B. K.		embryology of microchiroptera (Gopalakrishna) ..	93
Sitholey, R. V.—Study of fossil plants with reference to their structure and affinities in rela- tion to questions of plant evolution and palaeography ..	372	Studies on cytochemistry of hormone action (Kar) ..	41, 43, 177
Snake-bite. Studies in certain aspects of the chemistry and physiology of snake-bite (Research report) (Sarkar) ..	362	Subba Rao, K.—Colloids. (Research report) ..	352
Sodium hexametaphosphate. Preparation and properties ..	59	Subba Rao, K., Rao, M. B., Vasudevamurthy, A. R., and Sanjiva Rao, B.—Hysteresis in sorption XVII. Harden- ing of sericin and its influence on sorption-desorption hys- teresis ..	1
Soil conservation engineering (Vajda) ..	489	Subba Rao, K., Wajid, M. A. and Sanjiva Rao, B.—Changes in pH of the white and yolk of fertilized hen's egg during incubation in air, carbon di- oxide and liquid paraffin ..	5
Solids. Soft X-ray spectroscopic study. (Research report) (Das Gupta) ..	354	Subramaniam, M. K.—Cyto- genetics of yeast (Research report) ..	373
Solutions of algebraic difference equations, real and con- tinuous (Shah) ..	11	Subramanian, C. V.—Studies in fusaria from Indian soils, with special reference to physio- logical races (Research report)	369
Some factors concerning the transport of sediment by rivers (Auden) ..	501	Subramanyam, K.—An embryo- logical study of <i>Lerenhukia dubia</i> sord. in lehm ..	245
Sreeramamurty, K.—see Rama- sastry, C. and Sreeramamurty, K.		Sundaresan, M. K.—see Saha, N. K., Chanderskhara, B. S. and Sundaresan, M. K.	
Srivastava, B. N. and Saharia, V. N.—Construction of a com- bined vacuum furnace and mass spectrometer for universal use ..	263	Sunder Rao, Y.—Cytology of helobiales (Research report) ..	356
Stars. Internal constitution. (Research report) (Burman) ..	353	Symposium on Atmospheric Processes. Paper by S. P. Venkiteshwaran ..	19
Statistical thermodynamics and quantum electrodynamics. (Research report) (Auluck) ..	350	Symposium on multi-purpose river projects in India's national economy. Proceedings ..	375
Stipules of <i>Artocarpus integrifolia</i> L., <i>Ficus religiosa</i> L. and <i>Ficus elastica</i> Roxb. Origin, development and morphology (Mitra) ..	157	Synthesis of sesquiterpenes and the acids isolated from degeneration of these bodies (Research report) (Dutta) ..	370
Structure of the cuticles of <i>Dicroidium (thinnsfeldia)</i> fronds from the mesozoic of Australia (Jacob and Jacob, Mrs. C.) ..	101	Synthesis of steroid sex-hormones and hormones of adrenal cortex (Research report) (Mukherji) ..	364
Structure of the placenta in the Indian vampire bat, <i>Lyroderma lyra lyra</i> (Geoffroy) (Megader- matidae). Studies on the		Synthesis of the alicyclic systems related to the steroids (Research report) (Dutta) ..	370

	Page		Page
(<i>Thinnfeldia</i>). <i>Dicroidium</i> fronds from the mesozoic of Australia. A preliminary account of the structure of the cuticles (Jacob and Mrs. C. Jacob) ..	101	gas reaction (Research report) ..	360
Thiruvengkatachar, V. R.—Studies in compressible fluid flow (Research report) ..	357	Venkiteshwaran, S. P.—Winds at 10 kms. and above over India and its neighbourhood ..	19
Tilak, B. D.—Affinity of dyes for cellulose and proteins (Research report) ..	351	Voltage stabilizer. A simple form (Saha, Chandersekhara and Sundaresan) ..	127
Transport of sediment by rivers. Some factors (Auden) ..	501	Wajid, M. A.—see Subba Rao, K., Wajid, M. A. and Sanjiva Rao, K.	
Vacuum furnace and mass spectrometer. Construction of a combined vacuum furnace and mass spectrometer for universal use (Srivastava and Saharia) ..	263	West, W. D.—Mineral utilization	537
Vajda, A. de—Soil conservation engineering ..	489	White and yolk of fertilized hen's egg. Changes in pH, during incubation in air, carbon dioxide and liquid paraffin (Rao, Wajid and Rao) ..	5
Vasudevamurthy, A. R.—see Subba Rao, K., Rao, M. B., Vasudevamurthy, A. R. and Sanjiva Rao, B.		Winds at 10 kms. and above over India and its neighbourhood (Venkiteshwaran) ..	19
VedaRaman, S.—Adsorption of gases by industrially important catalysis and kinetics of		Yeast. Cytogenetics (Research report) (Subramaniam) ..	373
		Zinc bromide. Band spectrum of zinc bromide (Ramasastry and Sreeramamurty) ..	305

CONTENTS

No. 1, January-February.

	Page
Hysteresis in sorption XVII. Hardening of sericin and its influence on sorption—desorption <i>by</i> K. SUBBA RAO, M. B. RAO, A. R. VASUDEVA-MURTHY and B. SANJIVA RAO	1
Changes in pH of the white and yolk of fertilized hen's egg, during incubation in air, carbon dioxide and liquid paraffin <i>by</i> K. SUBBA RAO, M. A. WAJID and B. SANJIVA RAO	5
On real continuous solutions of algebraic difference equations (II) <i>by</i> S. M. SHAH	11
Winds at 10 kms. and above over India and its neighbourhood <i>by</i> S. P. VENKITESHWARAN	19
On the nephridia and coelomoducts of serpulimorpha and cirratulidae <i>by</i> G. KRISHNAN	29
Studies on cytochemistry of hormone action <i>by</i> A. B. KAR :	
Part I.—Alkaline phosphatase in the uropygial gland of normal and of androgen treated pigeons	41
Part II.—The distribution and concentration of alkaline phosphatase in the ovary of normal and of androgen treated pigeons	43
Luminescence spectra of alkali halides <i>by</i> H. N. BOSE and J. SHARMA	47
Studies in hexametaphosphates <i>by</i> R. C. MEHROTRA and N. R. DHAR :	
Part I.—Preparation and properties of sodium hexametaphosphate and a study of the extent of complex formation with calcium ions by conductivity data	59
Part II.—A study of the complexes formed by sodium hexametaphosphate with strontium, barium and lead ions by conductivity data	67

No. 2, March-April.

On the Nörlund summability of derived Fourier series <i>by</i> B. N. PRASAD and J. A. SIDDIQI	71
Bianchi's characteristic function in a congruence of Ribaucour <i>by</i> RAM BEHARI and R. S. MISHRA	83
The embryo sac of <i>Fritillaria liliacea</i> <i>by</i> J. S. AGRAWAL	87
Studies on the embryology of microchiroptera. Part VI. Structure of the placenta in the Indian vampire bat, <i>Lyroderma lyra lyra</i> (Geoffroy) (Mega-dermatidae) <i>by</i> A. GOPALAKRISHNA	93
On numbers which can be expressed by a given form <i>by</i> KULENDRA N. MAJUMDAR	99
A preliminary account of the structure of the cuticles of <i>Dicroidium</i> (thunfeldia) fronds from the mesozoic of Australia <i>by</i> K. JACOB and (MRS.) CHINNA JACOB	101
A simple form of voltage stabilizer <i>by</i> N. K. SAHA, B. S. CHANDERSEKHARA and M. K. SUNDARESAN	127

No. 3, May-June.

	Page
Physiological studies on the effect of colchicine on rice. II, by B. N. GHOSH ..	135
On a new type of partition by F. C. AULUCK, K. S. SINGWI and B. K. AGARWALA	147
Developmental studies. A comparative account of the origin, development and morphology of the stipules of <i>Artocarpus integrifolia</i> L., <i>Ficus religiosa</i> L. and <i>Ficus elastica</i> Roxb. by G. C. MITRA	157
Breeding habits, eggs and early life history of the Indian shad, <i>Hilsa ilisha</i> (Ham.), in the Nerbada river by C. V. KULKARNI	169
Studies on cytochemistry of hormone action. Part III. The effect of progesterone and desoxycorticosterone acetate on the distribution and concentration of alkaline phosphatase in the genital system of female pigeons by AMIYA B. KAR	177
On the larval development of the Indian transparent goby, <i>Gobiopsis chuno</i> (Hamilton), with observations on its bionomics by T. V. R. PILLAY and K. K. SAROJINI	181
Factory effluents from the Mettur Chemical and Industrial Corporation, Ltd., Mettur Dam, Madras, and their pollutional effects on the fisheries of the river Cauvery by S. V. GANAPATI and K. H. ALIKUNHI	189

No. 4, July-August.

First Chandra Kala Hora Memorial Lecture. Growth of the fishing industry: Sidelihts on fifteen years' work by S. B. SETNA	207
<i>In vivo</i> studies on the 'Anti-thiamine factor' in freshwater mussel (<i>Lamellidens marginalis</i>) by K. K. REDDI	221
Determination of elastic constants of solids by pulse method by KRISHNAJI ..	227
Elastic constants of some cubic nitrates by J. BHIMASENACHAR and T. SESHAGIRI RAO	235
Elastic constants of corundum by J. BHIMASENACHAR	241
An embryological study of <i>Levenhookia dubia</i> sond. in lehm by K. SUBRAMANYAM	245
The nonlinear method of circuit analysis by RAIS AHMAD	255
Construction of a new combined vacuum furnace and mass spectrometer for universal use by B. N. SRIVASTAVA and V. N. SAHARIA	263
Adaptive modifications in a hill-stream catfish, <i>Glyptothorax telchitta</i> (Hamilton) by BIMLA BHATIA	271
Cytological investigation of the mango (<i>Mangifera indica</i> L.) and the allied Indian species by S. K. MUKHERJEE	287
Band spectrum of zinc bromide by C. RAMASASTRY and K. SREERAMAMURTY	305

No. 5, September-October.

Proceedings of the Fifteenth Annual General Meeting, held at Poona on 2-1-1950	311
Presidential Address (Summary)	312
Annual Report, 1949	315
List of Fellows	324
Summaries of Research Reports of Research Fellows	350

No. 6, November-December.

Symposium Number

Symposium on 'Multi-purpose river projects in India's national economy'.

	<i>Page</i>
Introductory speech <i>by</i> B. C. GUBA	377
Principles of planning <i>by</i> K. SAIN	381
Problems of river forecasting in India <i>by</i> S. K. BANERJI	395
Hydrology <i>by</i> N. K. BOSE	421
The rôle of geology in multi-purpose projects <i>by</i> J. B. AUDEN	431
Design <i>by</i> K. L. RAO	443
Flood control <i>by</i> S. C. MAJUMDAR	463
Navigation <i>by</i> M. SINGH	469
Irrigation <i>by</i> M. SINGH	475
A pattern of land-use planning in the dry areas of the Bombay State <i>by</i> J. K. BASU and N. B. PURANIK	481
Soil conservation engineering <i>by</i> A. DE VAJDA	489
Agronomy and land utilization <i>by</i> R. J. KALAMKAR	495
Some factors concerning the transport of sediment by rivers <i>by</i> J. B. AUDEN	501
Sand-stowing <i>by</i> A. B. DUTT	513
Fisheries conservation and development <i>by</i> S. L. HORA	521
Power development <i>by</i> K. P. P. MENON	529
Mineral utilization <i>by</i> W. D. WEST	537
Mineral utilization <i>by</i> V. R. KHEDKAR	541
Cement and multi-purpose projects <i>by</i> J. B. AUDEN	545
Malaria and its control <i>by</i> B. C. DAS GUPTA	555
Rehabilitation in the Damodar Valley <i>by</i> K. S. V. RAMAN	565
Economic significance of the multi-purpose approach <i>by</i> S. N. MAJUMDAR	571
Appendix	577

HYSTERESIS IN SORPTION XVII. HARDENING OF SERICIN AND ITS INFLUENCE ON SORPTION-DESORPTION HYSTERESIS.*

By K. SUBBA RAO,† M. BHIMASENA RAO,‡ A. R. VASUDEVAMURTHY§ and
B. SANJIVA RAO,|| *Department of Chemistry, Central College,
Bangalore, S. India.*

(Received February 24; read March 4, 1949.)

INTRODUCTION.

The behaviour of cereals (Rao, K. S., 1939), gum arabic (Rao, K. S., 1940) and proteins (Rao, G. N., Rao, K. S. and Rao, B. S., 1947) in the sorption of water has been indicated. The hysteresis effect initially exhibited disappears after a certain number of cycles of sorption and desorption. This disappearance of the hysteresis effect is due to the swelling of the organo gels in water and the consequent loss of the entrapping effect.

Proteins can be hardened (Masami Oku and Jiro Hirose, 1938) by the various hardening reagents. The effect of hardening of sericin on the sorption-desorption hysteresis has been presented in this paper.

EXPERIMENTAL.

Extraction of sericin.

Sericin was extracted by heating raw silk in water at 120° C. in an autoclave. Sericin was precipitated from the colloidal solution by freezing and subsequent thawing. The precipitated sericin was separated and dried in air at room temperature for 48 hours.

Hardening of sericin.

Formaldehyde hardening.—Five grams of air dried sericin powder was put into 100 c.c. of 0.5% formaldehyde. The solution was acidified with hydrochloric acid to give a final concentration of 2%. The mixture was kept for 24 hours. The sericin was separated and dried.

Chrome hardening.—Basic chromium sulphate was prepared by mixing 50 c.c. of 0.1 molar chrome alum solution and 50 c.c. of 0.1N sodium hydroxide (Williamson, F. S., 1923). Five grams of sericin powder were kept in 100 c.c. of this basic chromium sulphate solution for 24 hours. After this treatment, sericin was separated, washed and dried in air at room temperature for 48 hours.

Sorption-desorption hysteresis.

The hardened as well as unhardened samples of sericin were dehydrated in vacuum at 60° C. for 6 hours. The dehydrated sericin was next introduced into the

* This investigation is a part of the programme of research work supported by the National Institute of Sciences of India, Delhi, by the award of a Senior Research Fellowship to one of the authors (K. Subba Rao, D.Sc.).

† Senior Scientist, Defence Science Organisation, Ministry of Defence, Government of India, New Delhi.

‡ Research Scholar, Central College, Bangalore.

§ Research Assistant, Indian Institute of Science, Bangalore.

|| Professor of Inorganic and Mineral Chemistry, Indian Institute of Science, Bangalore.

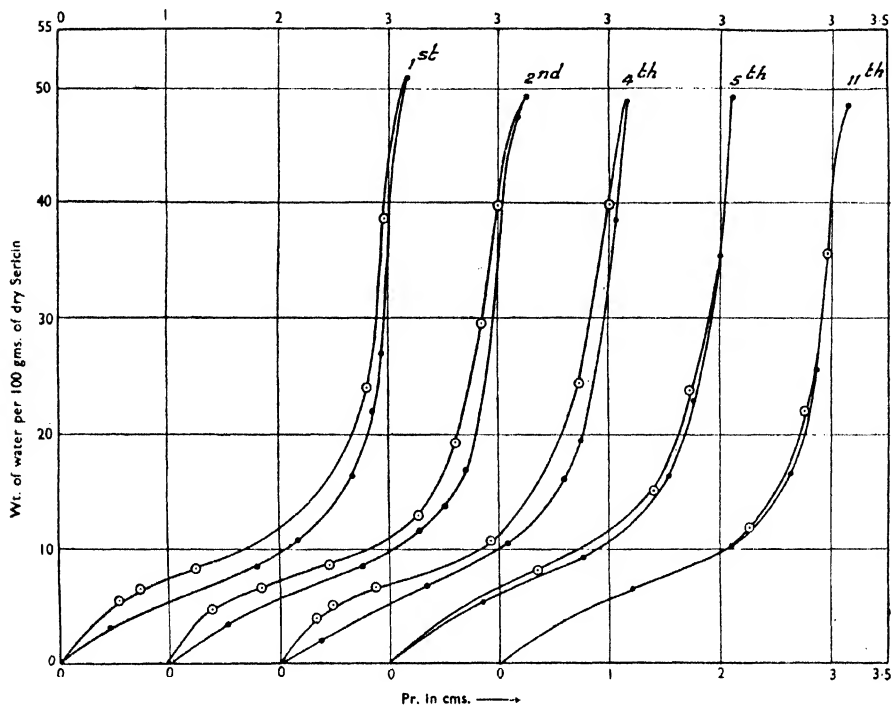


FIG. 1.

Sorption-desorption Hysteresis of water on unhardened sericin at the 1st, 2nd, 4th, 5th and 11th cycles.

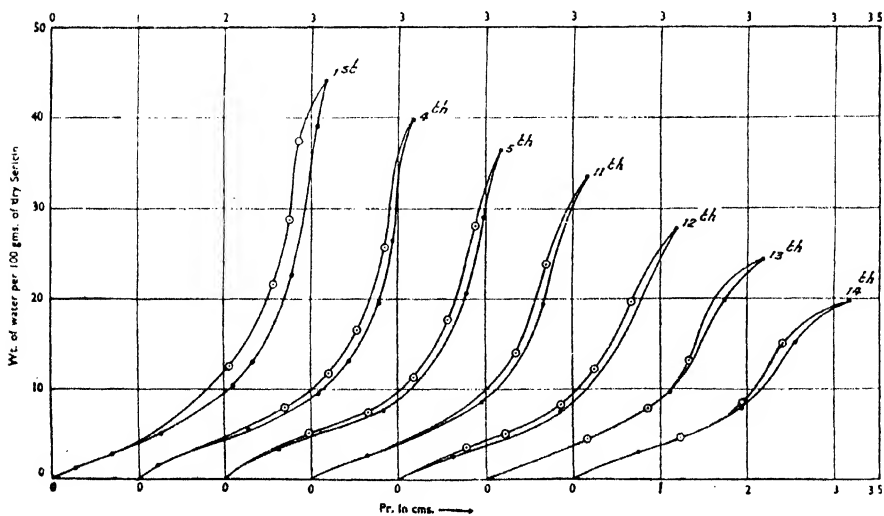


FIG. 2.

Sorption-desorption hysteresis of water on sericin (formaldehyde hardened) at the 1st, 4th, 5th, 11th, 12th, 13th and 14th cycles.

quartz fibre spring balance (Rao, K. S., 1941) and was subjected to successive sorption and desorption at 30° C. The results are indicated in Figs. 1-3. About 8-10 hours were allowed for the attainment of equilibrium and each cycle took about 8 days.

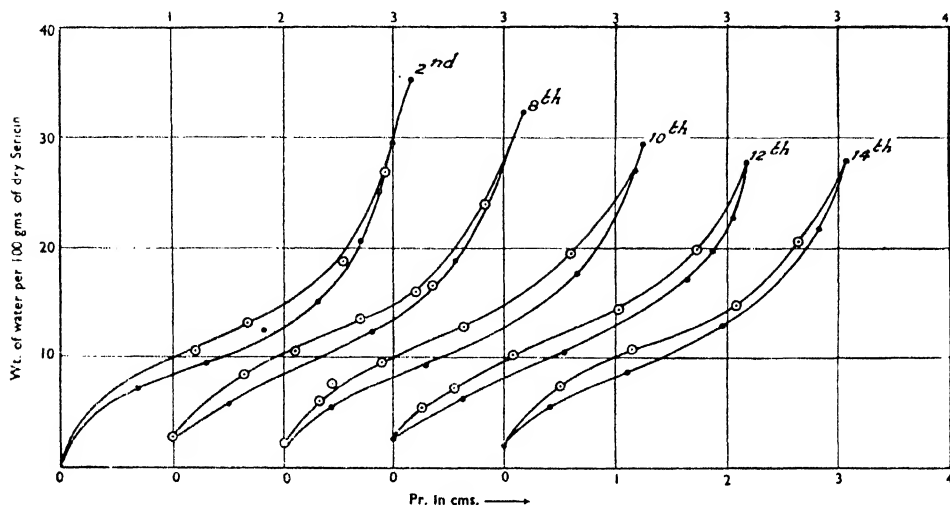


FIG. 3.

Sorption-desorption Hysteresis of water on sericin (Chrome hardened) at the 2nd, 8th, 10th, 12th and 14th cycles.

DISCUSSION.

Unhardened sericin.

Sericin like casein, egg albumen and gelatin (Rao, G. N., Rao, K. S. and Rao, B. S., 1947) exhibits the hysteresis effect in the initial stages, Fig. 1. The loop decreases in size on successive sorption and desorption and finally disappears.

The sorption and desorption processes were continued up to 11th cycle. In the dehydrated condition, sericin has cavities of fairly rigid walls. The cavities entrap water and cause hysteresis. On exposure of sericin to water vapour, water is absorbed and later imbibed. Sericin swells like other organo gels on the imbibition of water. The cavity walls now become elastic and yield during desorption. The cavities disappear. The entrapping effect is thus lost and hysteresis disappears.

Hardened sericin.

Sericin hardened by formaldehyde or by basic chromium sulphate behaves differently. In a series of sorption and desorption operations, the hardened sericin exhibits the hysteresis effect and the effect persists in the subsequent cycles of sorption and desorption. The sorption and desorption processes were continued up to 14th cycle, Figs. 2 and 3.

On hardening, sericin behaves more like a rigid gel. The swelling property is either lost or diminished. The rigidity of the cavity wall remaining practically unaltered on successive sorption and desorption, the cavities retain the entrapping effect and the hysteresis loop persists even after a number of cycles.

The above results in conjunction with those on grains (Rao, K. S., 1939, Rao, K. S., 1941), plant exudate (Rao, K. S., 1940) and proteins (Rao, G. N., Rao, K. S. and Rao, B. S., 1947) already published bring out clearly the rôle of the swelling property of the absorbent in the disappearance of the sorption-desorption hysteresis.

SUMMARY.

Sericin has been hardened by (1) formaldehyde and (2) basic chromium sulphate.

On the hardened and unhardened samples of sericin, sorption and desorption of water vapour at 30° C. have been conducted. Sericin hardened by formaldehyde or basic chromium sulphate shows the hysteresis effect which persists in the subsequent cycles. Whereas, the unhardened sericin shows a hysteresis loop which decreases in size in the subsequent cycles of sorption and desorption and finally disappears. These results indicate that hardened sericin behaves like a rigid gel, whereas unhardened sericin is an elastic gel like gelatin, casein, egg albumen and gum arabic.

REFERENCES.

- Masami Oku and Jiro Hirose (1938). Fixation of sericin of raw silk, II. Chrome fixation of isolated sericin. *J. Agr. Chem. Soc. Japan*, **14**, 178-186.
- Rao, K. S. (1939). Hysteresis in the sorption of water on rice. *Cur. Sci.*, **8**, 256.
- (1940). Elasticity of organo gels in relation to hysteresis in sorption. *Ibid.*, **9**, 19.
- (1941). Hysteresis in Sorptions I-VI. Permanence, Scanning, Drift and disappearance of the hysteresis loop. *J. Phys. Chem.*, **45**, 500-531.
- Rao, G. N., Rao, K. S. and Rao, B. S. (1947). Hysteresis in Sorption XV. Hysteresis in the sorption of water on casein, egg albumen and gelatin. *Proc. Ind. Acad. Sci.*, **25**, 221.
- Williamson, F. S. (1923). Basic chromic sulphate. *J. Phys. Chem.*, **28**, 384-8.

CHANGES IN pH OF THE WHITE AND YOLK OF FERTILIZED HEN'S EGG DURING INCUBATION IN AIR, CARBON DIOXIDE AND LIQUID PARAFFIN.*

By K. SUBBA RAO,† M. A. WAJID‡ and B. SANJIVA RAO,§
Department of Chemistry, Central College, Bangalore, S. India.

(Received February 24; read March 4, 1949.)

INTRODUCTION.

The study of the variation in pH is important in elucidating the mechanism of many natural biochemical processes. The pH of the constituents of hen's egg incubated in air has been reported by earlier workers (Baird, J. C. and Prentice, J. H., 1930; Gaggermeier, G., 1931; Needham, J., 1942a; Romanoff, A. L., 1944; Rubinstein, M., 1932; Sharp, P. F., 1929; Sharp, P. F. and Powell, C. K., 1931).

As means of preserving eggs from deterioration, dipping in oil or enclosing in an atmosphere of carbon dioxide immediately after the egg is laid has been suggested (Tauber, H., 1946). The change in pH of egg white and yolk during incubation in air, carbon dioxide and liquid paraffin has been studied and presented in this paper.

EXPERIMENTAL.

Fertilized eggs.

Fertilized eggs (as detected by an examination of the blastoderm) were selected for the study. In eggs incubated in air, the development of the blastoderm was rapid whereas in those incubated in carbon dioxide and liquid paraffin, development was inhibited.

Incubation of egg in air, carbon dioxide and liquid paraffin.

The egg, soon after it was laid, was put into an incubator. For incubation in carbon dioxide, the air in the incubator was replaced by carbon dioxide at atmospheric pressure. For incubation in liquid paraffin, the egg was placed in liquid paraffin in a bottle kept in the incubator. The temperature of the incubator was throughout kept at 41° C.

Glass electrode.

Sharp, P. F. and Powell, C. K. (1931) used a hydrogen electrode for the measurement of pH . On account of the high viscosity of the white and yolk, saturation with hydrogen was not possible. To overcome this difficulty the white and yolk were diluted. The error introduced by dilution was reported to be negligible. A glass electrode (Albert W. Davison, Henry S. van Klooster and Walter H. Bauer, 1941) was employed in the present work, as being most suitable

* This investigation is a part of the programme of research work supported by the National Institute of Sciences of India, Delhi, by the award of a Senior Research Fellowship to one of the authors (K. Subba Rao, D.Sc.).

† Senior Scientist, Defence Science Organisation, Ministry of Defence, Government of India, New Delhi.

‡ Research Fellow, Mysore University, Central College, Bangalore.

§ Professor of Inorganic and Mineral Chemistry, Indian Institute of Science, Bangalore.

from the standpoint of rapidity of work, accuracy and reproducibility. The electrometer circuit of the electrode included a Compton quadrant electrometer and a Tinsley's K-type vernier potentiometer. High tension was applied to the needle (Dole, M., 1941). The unknown potential was applied to one pair of quadrants, the other pair being earthed. In tapping out a known potential, the potentiometer permitted of an accuracy of 0.01 millivolt.

Measurement of pH.

At different stages of incubation, the eggs were removed, the white and the yolk were carefully separated by a hypodermic syringe and the pH was quickly determined. The attainment of equilibrium potential when the glass electrode was dipped in the test liquid was remarkably quick. Within two minutes steady values were obtained. The results are shown in Tables 1, 2 and 3 and Fig. 1. Acetate-hydrochloric acid (Britton, H. T. S., 1932*a*) and phosphate-borate (Britton, H. T. S., 1932*b*) buffers were employed as standards for purposes of comparison.

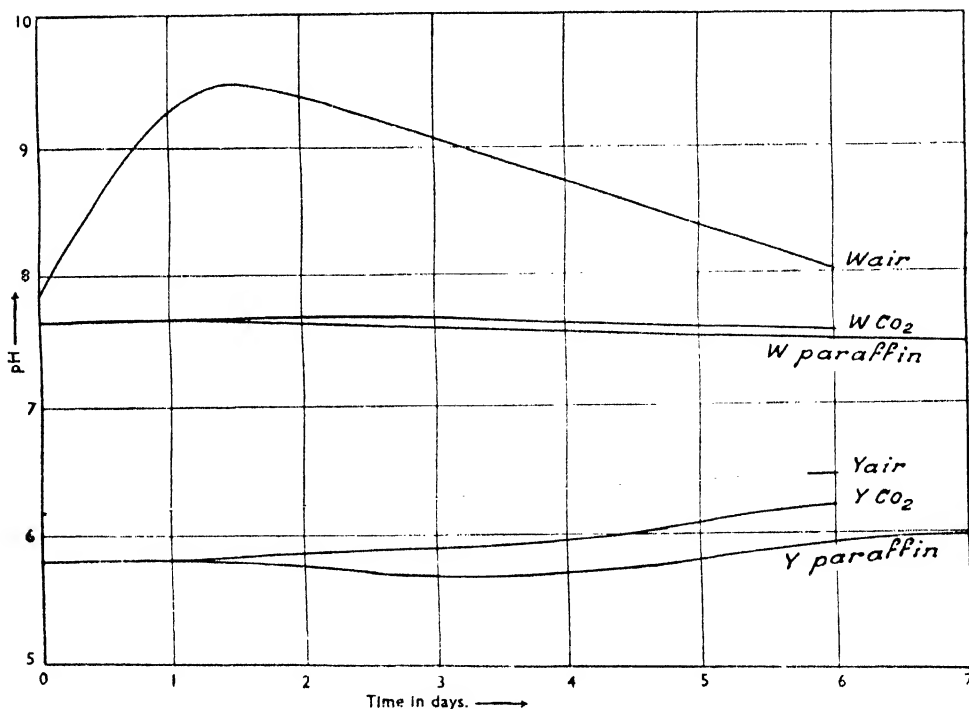


FIG. 1.

pH of white (W) and yolk (Y) of fertilized hen's egg incubated at 41° C. in air, carbon dioxide and liquid paraffin.

TABLE 1.

Variation in pH of white and yolk of fertilized hen's egg during incubation in air.

			Time of incubation.				
			Fresh.	1 day.	2 days.	3 days.	6 days.
1.	White	..	7.85	9.27	9.37	9.05	8.05
2.	Yolk	..	6.17	6.17	6.20	6.35	6.44

TABLE 2.

Variation in pH of white and yolk of fertilized hen's egg during incubation in carbon dioxide.

Fresh.			Time of incubation.					
			1 day.	2 days.	3 days.	4 days.	5 days.	6 days.
1. White	..	7.65	7.63	7.63	7.67	7.67	7.56	7.54
2. Yolk	..	5.84	5.85	5.88	5.90	5.99	6.11	6.19

TABLE 3.

Variation in pH of white and yolk of fertilized hen's egg during incubation in liquid paraffin.

Fresh.			Time of incubation.						
			1 day.	2 days.	3 days.	4 days.	5 days.	6 days.	7 days.
1. White	..	7.68	7.61	7.60	7.55	7.55	7.52	7.50	7.44
2. Yolk	..	5.85	5.84	5.79	5.70	5.74	5.82	5.91	5.93

DISCUSSION.

pH of white and yolk of egg incubated in air.

In fresh egg, the white has a pH 7.85 and the yolk 6.17. On continued incubation, the pH of white increases to a maximum of 9.5 up to 36 hours and decreases continuously thereafter. The pH of yolk, however, is practically constant up to the second day and later increases slowly but continuously. The yolk remains in the acid range, tending to become less acidic while the white is in the alkaline range tending to become less alkaline. The characteristic feature of the pH-time curve of egg white is the hump. The significance of this hump and the nature of the continuous variation in pH with time, of egg white and yolk during incubation, are of interest.

These changes in pH of white and yolk are naturally connected with the metabolic processes occurring within the egg during incubation.

The egg is a highly complex system and is known to consist of a variety of substances—carbohydrates, proteins, enzymes, minerals, vitamins and fats in different amounts. Scholl, H. (1893) showed that fresh egg white contained a considerable amount of carbon dioxide and that the major portion of it was present as bicarbonate. These bicarbonates are mainly of potassium and sodium (Healy, D. J. and Peter, A. M., 1925). Brooks, J. and Pace, J. (1938) report that there is little or no carbamino-carbon dioxide.

Before the egg is laid, the constituents of the egg have a partial pressure of carbon dioxide corresponding to that of the body tissue of the hen (Aggazzotti, A., 1914). The partial pressure of carbon dioxide in the atmosphere being very much less, the egg white loses its carbon dioxide through the pores of the shell immediately after the egg is laid. This results in an initial increase in the pH. The loss of carbon dioxide is fairly rapid as indicated by the steepness of the curve. The portion of carbon dioxide that escapes, probably exists in the white in free condition, because no carbonic anhydrase activity has been noticed in the early stages of development of the Chick embryo. In 36 hours, the pH reached a maximum of 9.6. By this time, the natural metabolic processes will have commenced in the egg under aerobic conditions, at the temperature of incubation. The cells respire, oxygen is taken in and carbon dioxide is produced. The subsequent fall in pH is due to the accumulation of carbon dioxide in the white.

In the early stages of development, the diet of the embryo is mostly carbohydrate and relatively small amount of protein. After about the fifth day, fat and protein enter the embryo in large amounts (Needham, J., 1942b). The

digestive work borne by the yolk in the early stages of development involves a powerful enzymic equipment.

The respiratory quotient of the blastoderm of the hen's egg is invariably in the neighbourhood of unity during the first week of development and this indicates that the component of the diet combusted is mostly carbohydrate.

The small increase in pH of the yolk during incubation may be due to protein catabolism resulting in the production of ammonia (Needham, J., 1942c).

pH of the white and yolk of egg incubated in carbon dioxide and liquid paraffin.

The pH-time curve of white and yolk of eggs incubated in carbon dioxide and liquid paraffin are practically coincident. The pH of white suffers a very small but continuous decrease. The conditions are essentially anaerobic. In the absence of oxygen, the metabolic processes of the hen's egg are inhibited. A small increase in the size of the blastoderm indicates the existence of slight metabolic activity. The small increase in the acidity of the white is probably due to anaerobic glycolysis (Needham, J., 1942c).

As in air-incubation, the small increase in pH, after the third day, of the yolk of egg incubated in carbon dioxide or in liquid paraffin is due to protein catabolism.

Carbon dioxide and liquid paraffin as preservatives for egg.

Carbon dioxide and liquid paraffin are good preservatives for eggs against deterioration, because in eggs preserved in these substances, the white and yolk suffer no appreciable change in consistency and appearance and develop no odour. Though in large doses carbon dioxide has an inhibiting effect, it is of interest to note that in moderate doses the gas is found to have a stimulating effect on the growing embryo (Romanoff, A. L. and Romanoff, A. J., 1933).

The foregoing considerations reveal that the change in pH of the constituents of the egg is the resultant effect of various metabolic processes in the egg.

SUMMARY.

By employing a glass electrode, the variation in pH of the white and yolk of fertilized hen's egg during incubation in air, carbon dioxide and liquid paraffin has been studied.

In eggs incubated in air, the white shows an initial rise in pH due to the escape of carbon dioxide and a subsequent steady fall after 36 hours owing to carbohydrate catabolism. The yolk has a constant pH up to the second day and later, this gradually rises owing to protein catabolism.

When incubated in carbon dioxide or in liquid paraffin, the white suffers a small but continuous fall in pH, whereas the yolk shows a rise in pH. This is due to the inhibition of the normal metabolic processes in the egg.

REFERENCES.

- Aggazzotti, A. (1914). Arch. Entwicklungsmech. *Organ.*, **40**, 65-97.
 Albert, W. Davison, Henry, S. van Klooster and Walter, H. Bauer (1941). Laboratory Manual of Physical Chemistry. John Wiley and Sons Inc., New York, p. 207.
 Baird, J. C. and Prentice, J. H. (1930). The changes with age of the Hydrogen-ion concentration of egg white and egg yolk and of the refractive index of the egg white. *Analyst.*, **55**, 20-23.
 Britton, H. T. S. (1932a). Hydrogen-ions. Van Nostrand Co. Inc., New York, p. 217.
 ——— (1932b). Hydrogen-ions. Van Nostrand Co. Inc., New York, p. 221.
 Brooks, J. and Pace, J. (1938). Distribution of carbon dioxide in the hen egg. *Proc. Roy. Soc. (London)*, **B126**, 196-210.
 Dole, M. (1941). The glass electrode. John Wiley and Sons Inc., New York, p. 40.
 Gaggermeier, G. (1931). Experiments to determine the freshness of chicken eggs. *Arch. Reichsgesundh.*, **63**, 489-97.

- Healy, D. J. and Peter, A. M. (1925). The Hydrogen-ion concentration and basicity of egg yolk and egg white. *Am. J. Physiol.*, **74**, 363-8.
- Needham, J. (1942a). *Biochemistry and Morphogenesis*. Macmillan, New York, p. 11.
- (1942b). *Biochemistry and Morphogenesis*. Macmillan, New York, p. 72.
- (1942c). *Biochemistry and Morphogenesis*. Macmillan, New York, p. 592.
- Romanoff, A. L. (1944). Hydrogen-ion concentration of albumin and yolk of the developing avian egg. *Biol. Bull.*, **87**, 223-6.
- Romanoff, A. L. and Romanoff, A. J. (1933). Biochemistry and biophysics of the developing hen's egg, II. Influence of composition of air. *Cornell Univ. Agr. Expt. Sta. Mem.*, **150**, 3-36.
- Rubinstein, M. (1932). Changes in the pH of the constituents of hen eggs during incubation. *Compt. Rend. Soc. Biol.*, **111**, 60-62.
- Sharp, P. F. (1929). The pH of the white as an important factor influencing the keeping quality of hen eggs. *Science*, **69**, 278-80.
- Sharp, P. F. and Powell, C. K. (1931). Increase in the pH of the white and yolk of hen eggs. *Ind. Eng. Chem.*, **23**, 196-9.
- Scholl, H. (1893). *Arch. Hyg.*, **17**, 535-51.
- Tauber, H. (1946). *Enzyme Technology*. John Wiley and Sons Inc., New York, p. 188.

ON REAL CONTINUOUS SOLUTIONS OF ALGEBRAIC DIFFERENCE EQUATIONS (II).

By S. M. SHAH, *Muslim University, Aligarh.*

(Communicated by Prof. Ram Behari, F.N.I.)

(Received April 21; read November 25, 1949.)

1. INTRODUCTION.

Let $y(x)$ be a real continuous solution of an algebraic difference equation of the first order

$$(1) \quad P(y(x+1), y(x), x) = \sum a x^\alpha y(x)^{\beta_0} y(x+1)^{\beta_1} = 0.$$

I have shown that* $\liminf_{x \rightarrow \infty} \log \log |y(x)|/x < \infty$.

This relation is the best possible. If we suppose that

$$(2) \quad y(x) \text{ is a monotone function of } x \text{ for } x > x_0,$$

then $\limsup_{x \rightarrow \infty} \log \log |y(x)|/x < \infty$.

In this paper I replace the condition (2) by a weaker condition. We shall suppose, in what follows, that $y(x)$ is real and continuous† for $x > x_0$.

THEOREM 1. *If $y(x)$, a solution of an algebraic difference equation $P = 0$ of the first order, be such that‡*

$$(3) \quad y(x+h) \geq y(x)/e_2(Bx), \quad 0 \leq h \leq 1, x > x_0,$$

where B is a positive constant, then

$$y(x) < e_2(Ax) \text{ for all } x > x_0(A),$$

where $A (> B)$ is a constant depending on the given equation.

REMARK. Solutions satisfying condition (3) may exist. Consider, for instance, the equation §

$$(4) \quad (y(x) - x^b)(y(x+1) - (x+1)^b) = 0.$$

This equation is satisfied by a continuous function $y(x)$ defined as follows :

$$\begin{aligned} y(x) &= x^b, \quad \text{for } 2n-1 \leq x \leq 2n, \\ &= (2n)^b + 2 \left\{ \left(2n + \frac{1}{2}\right)^b e_2\left(2n + \frac{1}{2}\right) - (2n)^b \right\} (x-2n), \quad \text{for } 2n \leq x \leq 2n + \frac{1}{2}, \\ &= (2n+1)^b + 2 \left\{ (2n+1)^b - \left(2n + \frac{1}{2}\right)^b e_2\left(2n + \frac{1}{2}\right) \right\} (x-2n-1), \\ &\quad \text{for } 2n + \frac{1}{2} \leq x \leq 2n+1. \end{aligned}$$

* See Ref. 2, pp. 548-9. There is a misprint in the last line of p. 558. Read (29) instead of (30).

† x_0 is not necessarily the same at each occurrence.

‡ $e_2(x)$ denotes $\exp(\exp x)$.

§ Ref. 2, p. 549.

This function $y(x)$ satisfies the condition

$$y(x+h) \geq y(x)/e_2(x), \quad 0 < h \leq 1, x > x_0.$$

2. EQUATIONS WITH POLYNOMIAL COEFFICIENTS.

Let $P_r(x)$ and $Q(x)$ be polynomials in x of degree p_r and q respectively.

THEOREM 2. Let $\Psi(x)$ be any increasing function such that

$$\lim_{x \rightarrow \infty} \Psi(x) = \infty, \quad \lim_{x \rightarrow \infty} \log \Psi(x)/\log x = 0$$

and let $y(x)$ be a solution of the equation

$$(5) \quad P_m(x)y(x+m) + \dots + P_0(x)y(x) = Q(x).$$

$$\text{Let } a = \max \{ |p_0 - p_m|, \dots, |p_{m-1} - p_m|, |q - p_m| \}.$$

If $y(x)$ satisfies the condition

$$(6) \quad y(x+h) \geq y(x)/\Psi(x), \quad \text{for } 0 < h \leq 1, x > x_0,$$

$$\text{then } y(x) < \exp(Ax \log x), \quad \text{for } x > x_0(A),$$

where A is any constant greater than a .

COR. If $y(x)$, a non-decreasing function of x , be a solution of (5), then

$$y(x) < \exp(Ax \log x), \quad x > x_0(A),$$

where A is any constant greater than a .

THEOREM 3. If $y(x)$, a solution of the equation

$$(7) \quad P_1(x)y(x+1) + P_0(x)y(x) = Q(x),$$

satisfies either the condition (6) or the condition

$$\liminf_{x \rightarrow \infty} y(x)\Psi(x) > 0,$$

then

$$(8) \quad y(x) < \exp(Ax \log x), \quad \text{for } x > x_0(A),$$

where A is any constant greater than $\max \{ |p_0 - p_1|, |q - p_1| \}$.

COR. Any solution $y(x)$ of (7) satisfies

$$\liminf_{x \rightarrow \infty} \log |y(x)| / x \log x \leq A.$$

If in the equation (7), $Q(x) = 0$ and

$$P_0(x)/P_1(x) = -c \prod_1^{p_0} (x - \alpha_r) / \prod_1^{p_1} (x - \beta_r)$$

then *

$$y(x) = \tilde{\omega}(x)c^x \prod_1^{p_0} \Gamma(x - \alpha_r) / \prod_1^{p_1} \Gamma(x - \beta_r),$$

where $\tilde{\omega}(x)$ is any arbitrary periodic function. Since $\log \Gamma(x) \sim x \log x$, we see that (8) gives a 'best possible' upper bound.

3. EQUATIONS OF ORDER m .THEOREM 4. *Let*

$$(9) \quad P(y(x+m), \dots, y(x), x) = \sum a x^\alpha y(x)^{\beta_0} \dots y(x+m)^{\beta_m} = 0$$

be an algebraic difference equation of order m and let

$$T' = a' x^{\alpha'} y(x)^{\beta'_0} \dots y(x+m)^{\beta'_m}$$

be the principal term and let the terms of the equation be so related that when $\beta'_m = \beta_m$ then either

$$\beta'_{m-1} > \beta_{m-1} \text{ or } \beta'_{m-2} = \beta_{m-1} \text{ and } \beta'_i > \beta_i, \quad (i = 0, 1, 2, \dots, m-2).$$

If $y(x)$ be a solution such that it satisfies the conditions (3) and

$$(10) \quad \log y(x)/\log x \rightarrow \infty \text{ as } x \rightarrow \infty,$$

then $y(x) < e_2(Ax)$, for all $x > x_0(A)$,

where $A (> B)$ is a constant depending on the given equation.

COR. 1. If $y(x)$, a solution of an algebraic difference equation of the second order, satisfies the conditions (3) and (10), then $y(x) < e_2(Ax)$, for all $x > x_0(A)$.

COR. 2. If $y(x)$, a solution of an algebraic difference equation of the second order, satisfies the condition (3), then

$$(11) \quad y(x) < e_2(Ax), \text{ for a sequence of values of } x \rightarrow \infty.$$

4. LEMMA 1.

If $f(x)$ is continuous for $x > x_0$ and $f(x) \geq \exp(Ax \log x)$, $A > 0$, for a sequence of values of x tending to infinity, then there exists a sequence of numbers x_n tending to infinity such that

$$f(x+1) \geq x^A f(x) \text{ for } x = x_1, x_2, \dots$$

The proof is similar to that of Lemma 1 (Ref. 2, p. 550) and is omitted.

5. LEMMA 2.

Let $f(x)$ be continuous for $x > x_0$ and let

$$(12) \quad \limsup_{x \rightarrow \infty} \log \log f(x)/x \geq A > 0.$$

Let B be any positive constant less than A and suppose $f(x)$ satisfies the condition

$$(13) \quad f(x+h) \geq f(x)/e_2(Bx), \quad 0 < h \leq 1, x > x_0,$$

then there exists a sequence of numbers $x_n \rightarrow \infty$ such that

$$(14) \quad f(x) \geq e_2(cx); f(x+1) \geq \{f(x)\}^{\exp c},$$

where c is any positive constant such that $B < c < A$, for $x = x_1, x_2, \dots$

PROOF. If $f(x) \geq e_2(cx)$ for all large x , then the result follows from Lemma 1 (Ref. 2, p. 550). Suppose therefore that $f(x) < e_2(cx)$ for a sequence of values of $x \rightarrow \infty$. Let $F(x) = f(x)/e_2(cx)$ and $X > x_0$ be an arbitrary large number such that $F(X) < 1$. Take $Y > X$ such that

$$(i) \log \log f(Y) > \frac{1}{2}(A+c)Y,$$

$$(ii) \frac{A-c}{2} Y + \log \left(1 - \frac{\exp(BY)}{\exp((A+c)Y/2)} \right) - c > 0.$$

This is possible since $\limsup_{x \rightarrow \infty} \log \log f(x)/x > (A+c)/2$. Hence $F(Y) > 1$. Let Z be the largest number such that $X < Z < Y$, and $F(Z) = 1$. Since $F(x)$ is continuous for $x \geq X$, Z exists and $F(x) \geq 1$ for $Z \leq x \leq Y$. Consider

$$f(Z), f(Z+1), \dots, f(Z+m)$$

where $Y \leq Z+m < Y+1$. Now

$$\begin{aligned} \log \log f(Z+m) &\geq \log \{ \log f(Y) - \exp(BY) \} \\ &= \log \left\{ \log f(Y) \left(1 - \frac{\exp(BY)}{\log f(Y)} \right) \right\} \\ &= \log \log f(Y) + \log \left(1 - \frac{\exp(BY)}{\log f(Y)} \right) \\ &> \frac{A+c}{2} Y + \log \left(1 - \frac{\exp(BY)}{\exp((A+c)Y/2)} \right). \end{aligned}$$

Also

$$\begin{aligned} \frac{A+c}{2} Y &= cY + \frac{A-c}{2} Y > c(Z+m-1) + \frac{A-c}{2} Y \\ &= \log \log f(Z) + c(m-1) + \frac{A-c}{2} Y; \end{aligned}$$

and so from (ii)

$$\log \log f(Z+m) - \log \log f(Z) > cm.$$

Hence at least one of the values

$$\log \log f(Z+n) - \log \log f(Z+n-1), \quad n = 1, 2, \dots, m,$$

is greater than c . If

$$\log \log f(Z+N) - \log \log f(Z+N-1) > c$$

then

$$\begin{aligned} f(Z+N-1) &> e_2(c(Z+N-1)) \\ f(Z+N) &\geq \{f(Z+N-1)\}^{\exp c} \end{aligned}$$

which proves the lemma.

6. LEMMA 3.

If $f(x)$ is continuous for $x > x_0$ and satisfies conditions (12) and (13), then there exists a sequence of numbers $x_n \rightarrow \infty$ such that

$$(15.1) \quad f(x+1) \geq e_2(Dx)$$

$$(15.2) \quad f(x+1) \geq \{f(x)\}^{\exp(D/2)}$$

$$(15.3) \quad f(x+2) \geq \{f(x+1)\}^{\exp(D/2)}$$

for $x = x_1, x_2, \dots$, D being any constant such that $B < D < A$.

The proof depends on the relation (14) proved above and is similar to that of Lemma 3 (Ref. 2, pp. 551-2).

REMARK. (i) If we assume that instead of condition (13) $f(x)$, in Lemma 2, satisfies

$$(13') \quad f(x+h) \geq f(x)/e_2(Ax), \quad 0 \leq h \leq 1, x \geq x_0,$$

the conclusions (14), or (15), do not follow. Consider, for instance, $f(x)$ defined as follows. Let $x_n = n!^{n!}$ and

$$\begin{aligned} f(x) &= 1, & \text{for } x_{n-1} + \frac{1}{4} \leq x \leq x_n - \frac{1}{4}, \\ &= 1 + 4(e_2(x_n) - 1)(x - x_n + \frac{1}{4}), & \text{for } x_n - \frac{1}{4} \leq x \leq x_n, \\ &= 1 - 4(e_2(x_n) - 1)(x - x_n - \frac{1}{4}), & \text{for } x_n \leq x \leq x_n + \frac{1}{4}. \end{aligned}$$

Here $A = 1$ and (13') is always satisfied. Further, (12) holds but there is no sequence $X_n \rightarrow \infty$ such that

$$f(x) \geq e_2(\delta x), f(x+1) \geq \{f(x)\}^{\exp \delta},$$

where δ is any positive number, for $x = X_1, X_2, \dots$.

(ii) Under the given hypotheses (12) and (13) it is not possible to obtain inequalities (14) satisfied for all $x > x_0$, or to obtain inequalities of the type (14), with c replaced by A , satisfied by a sequence of values of x tending to infinity. We can easily construct a suitable function by taking points on the curves $y = e_2(Ax)$, $y = e_2(Ax)/e_2(Bx)$ and joining them by a straight line.

7. LEMMA 4.

Let $\phi(x)$ be an increasing continuous function for $x > x_0$ such that

$$\lim_{x \rightarrow \infty} \phi(x) = \infty, \lim_{x \rightarrow \infty} \frac{\log \phi(x)}{x \log x} = c, \quad 0 \leq c < \infty.$$

Let $f(x)$ be continuous and

$$f(x+h) \geq f(x)/\phi(x), \quad 0 \leq h \leq 1, x \geq x_0,$$

and $\log f(x)/x \log x \geq A > c$, for a sequence of values of $x \rightarrow \infty$, then there exists a sequence $x_n \rightarrow \infty$ such that

$$f(x) \geq \exp(Bx \log x), \quad f(x+1) \geq x^B f(x)$$

where B is any positive constant less than $A - c$, for $x = x_1, x_2, \dots$.

PROOF. Write $B = A - d$. Then $d > c$. If $f(x) \geq \exp(Bx \log x)$ for $x > x_0$, then the result follows from Lemma 1. Suppose therefore that $f(x) < \exp(Bx \log x)$ for a sequence of values of $x \rightarrow \infty$. Let $F(x) = f(x)/\exp(Bx \log x)$ and choose $X > x_0$ such that $F(X) < 1$. Take $Y > X$ such that

$$(i) \quad \log \phi(Y) < \frac{d+c}{2} Y \log Y,$$

$$(ii) \quad \frac{Y \log Y}{(Y+1) \log(Y+1)} > \frac{B}{\left(A - \frac{d+c}{2}\right)},$$

$$(iii) \quad \log f(Y) \geq AY \log Y.$$

• The result now follows as in Lemma 2.

8. PROOF OF THEOREM 1.

Let T' denote the principal term and T any other term of $P = 0$. Dividing throughout by T' we have ratios of the type

$$(16.1) \quad b \left\{ \frac{x^{K_0} y(x)^{K_1}}{y(x+1)} \right\}^{\beta'_1 - \beta_1}, \quad \beta'_1 > \beta_1,$$

$$(16.2) \quad b \left\{ \frac{x^{K_0}}{y(x)} \right\}^{\beta'_0 - \beta_0}, \quad \beta'_0 > \beta_0,$$

$$(16.3) \quad bx^{\alpha - \alpha'}, \quad \alpha' > \alpha.$$

Let K be the $\max |K_1|$ for all the ratios of type (16.1) and let $A = 1 + \max(1, B, \log K)$. If $y(x) \geq e_2(Ax)$ for a sequence of values of $x \rightarrow \infty$, then by Lemma 2, we can find a sequence $x_n \rightarrow \infty$ such that

$$y(x) \geq e_2(x), y(x+1) > \{y(x)\}^{\exp c},$$

where $c = \frac{1}{2} + \max(1, B, \log K)$ for $x = x_n$. Hence the ratios of the types (16.1), (16.2) and also (16.3) tend to zero as $x = x_n \rightarrow \infty$, and so we have a contradiction. Hence $y(x) < e_2(Ax)$ for $x > x_0(A)$.

9. PROOF OF THEOREM 2.

Let $A = k + a$ ($k > 0$). From the given equation we have

$$(17) \quad 1 + \frac{P_{m-1}(x)y(x+m-1)}{P_m(x)y(x+m)} + \dots + \frac{P_0(x)y(x)}{P_m(x)y(x+m)} = \frac{Q(x)}{P_m(x)y(x+m)}.$$

If $y(x) \geq \exp(Ax \log x)$ for a sequence of values of $x = x_n \rightarrow \infty$, we have by Lemma 4

$$\begin{aligned} \text{and} \quad y(x+m) &\geq (x+m-1)^B y(x+m-1), \\ y(x+m-1) &\geq \exp(x+m-1), \end{aligned}$$

where $B = a + \frac{1}{2}k$, for a sequence of values of $x = X_n \rightarrow \infty$.

Hence if $x = X_n$, then

$$\begin{aligned} \left| \frac{P_{m-1}(x)y(x+m-2)}{P_m(x)y(x+m)} \right| &< c_1 x^{p_{m-1}-p_m} \frac{y(x+m-1)}{y(x+m)} \\ &< c_1 x^{p_{m-1}-p_m-B} \rightarrow 0, \quad \text{as } x = X_n \rightarrow \infty \\ \left| \frac{P_{m-2}(x)y(x+m-2)}{P_m(x)y(x+m)} \right| &< c_1 x^{p_{m-2}-p_m} \frac{y(x+m-1)\psi(x+m-2)}{y(x+m)} \\ &< c_1 x^{(p_{m-2}-p_m+\frac{k}{4}-B)} \rightarrow 0 \quad \text{as } x = X_n \rightarrow \infty. \end{aligned}$$

Similarly, the remaining ratios on the left-hand side of (17) tend to zero as $x = X_n \rightarrow \infty$. Further

$$\left| \frac{Q(x)}{P_m(x)y(x+m)} \right| < c_1 x^{q-p_m} \frac{1}{y(x+m)} \rightarrow 0, \quad \text{as } x = X_n \rightarrow \infty.$$

Hence we have a contradiction and so $y(x) < \exp(Ax \log x)$, $x > x_0$ which proves the theorem.

The corollary follows from the theorem. Theorem 3 and its corollary follow immediately from Lemma 1.

10. PROOF OF THEOREM 4.

The ratios T/T' take the forms

$$(18.1) \quad b \left\{ \frac{x^{K_0} y(x)^{K_1} \dots y(x+m-1)^{K_m}}{y(x+m)} \right\}^{\beta'_m - \beta_m} \quad \beta'_m > \beta_m,$$

$$(18.2) \quad b \left\{ \frac{x^{p_0} y(x)^{p_1} \dots y(x+m-2)^{p_{m-1}}}{y(x+m-1)} \right\}^{\beta'_{m-1} - \beta_{m-1}}, \quad \beta'_{m-1} > \beta_{m-1},$$

$$(18.3) \quad b \left\{ \frac{x^{k_0}}{y(x)^{k_1} \dots y(x+m-2)^{k_{m-1}}} \right\},$$

respectively, where k_1, k_2, \dots are all non-negative constants and k_0 is negative if all k_1, \dots, k_{m-1} are zero. Let

$$|K_1| + \dots + |K_m| = A_m,$$

$$|p_1| + \dots + |p_{m-1}| = B_m;$$

and let α_1 be $\max A_m$ for all ratios of the type (18.1) and let α_2 be $\max B_m$ for all ratios of the type (18.2) and let $a = \max(1, B, \log \alpha_1, \log \alpha_2)$, $A = 1 + 2a$. If $y(x) > e_2(Ax)$ for a sequence of values of $x \rightarrow \infty$, then by Lemma 3 we can choose a sequence (x_n) such that

$$y(x+1) > e_2(Dx),$$

$$y(x+1) > \{y(x)\}^{\exp(D/2)},$$

$$y(x+2) > \{y(x+1)\}^{\exp(D/2)},$$

where $D = \frac{1}{2} + 2a$, for $x = x_n \rightarrow \infty$. By hypothesis (10) all ratios of the type (18.3) tend to zero as $x \rightarrow \infty$. Further

$$y(x+m-2) < y(x+m-1)e_2(B(x+m-2)),$$

$$y(x+m-3) < y(x+m-2)e_2(B(x+m-3)),$$

and so on. Hence for $x = x_n + 2 - m$, we have

$$x^{K_0} y(x)^{K_1} \dots y(x+m-1)^{K_m} < y(x+m-1)^{\alpha_1} \{e_2(B(x+m-1))\}^\Delta,$$

where Δ is a constant. Further

$$x^{p_0} y(x)^{p_1} \dots y(x+m-2)^{p_{m-1}} \leq y(x+m-2)^{\alpha_2} \{e_2(B(x+m-2))\}^\Delta.$$

Hence the ratios of the type (18.1) and (18.2) tend to zero as $x = x_n + 2 - m \rightarrow \infty$. Thus we have a contradiction and so $y(x) < e_2(Ax)$ for $x > x_0(A)$.

Corollary 1 follows immediately since when $\beta'_2 = \beta_2$ then either $\beta'_1 > \beta_1$ or $\beta'_1 = \beta_1$ and $\beta'_0 > \beta_0$.

To prove Corollary 2, suppose, if possible, that (11) is false. Then

$$(19) \quad y(x) > e_2(Ax) \text{ for } x > x_0.$$

Hence both conditions (3) and (10) are satisfied and from Corollary 1 we have $y(x) < e_2(Ax)$ for $x > x_0$, which contradicts (19), and Corollary 2 is proved.

REFERENCES.

1. Milne Thomson, L. M. (1933). *Calculus of Finite Differences*.
2. Shah, S. M. (1947). On Real Continuous Solutions of Algebraic Difference Equations. *Bull. Amer. Math. Soc.*, **53**, 548-558.

WINDS AT 10 KMS. AND ABOVE OVER INDIA AND ITS NEIGHBOURHOOD.

By S. P. VENKITESHWARAN.

(Communicated by Dr. S. K. Banerji, D.Sc., F.N.I.)

(Read at the Symposium on 'Atmospheric Processes', held at Bombay on 30-31 August, 1946 ; received for publication on 2-6-1949.)

ABSTRACT.

Upper winds from the surface to 8 kms. over India have been analyzed by Dr. Ramanathan and Mr. Ramakrishnan. The present paper summarizes all data available during the period 1920 to 1941 for the levels above 8 kms. Charts showing the general circulation of winds for every 2 kms. level from 10 to 20 kms. are drawn. These Charts show the strength and direction of the Westerlies during the winter months and the Easterlies during the monsoon months. The charts for the transitional months indicate the replacement of one set of general circulation by the other. The zonal components of the winds over India at all levels from 5°N. to 25°N. drawn for the two representative months February and August compared with those drawn by Bjerknes from an analysis of the upper air pressure distribution show similarity. The paper also illustrates the variation of wind with height over different regions in different seasons.

Upper wind circulation over India and its neighbourhood up to 8 kms. has been analyzed and discussed by K. R. Ramanathan and K. P. Ramakrishnan (1939). Recently, during the war, more up-to-date charts analyzing all available data over India and its neighbouring countries, viz. Russia, Iraq, Arabia, Malaya, Siam, Indo-China and China have been published (1943). These also give the upper air circulation up to 8 kms. only. Demand for information regarding the upper air circulation at much higher levels has, however, increased recently due to the increase in the levels of flying that can be usually attained by aeroplanes and due to attempts at stratospheric and rocket flying. There is no analysis on this subject for India except that by N. K. Sur (1930) over a single station, viz. Agra. The present paper summarizes briefly all the available data above 8 kms. over India and its neighbourhood.

The resultant monthly direction and velocities and the average speeds irrespective of direction together with a number of observations at each km. level up to the maximum height for which it is available for all Pilot Balloon Observatories under the India Meteorological Department are published annually. All such data for the period 1920 to 1941 were tabulated and analyzed.

In summarizing the data, the observations made during the different parts of the day have not been separated out, and all available data have been taken into account. There seems to be no objection to this as the diurnal variation at such high levels will be negligible; the number of occasions with two high flights on the same day at one station will also be negligible, because for most of the period for which the data have been analyzed, either the morning or the afternoon flight was restricted to expedite supply of data to different customers, particularly the aviators. There was also the limitations imposed by the diurnal variation of cloud and visibility.

Different types of balloons have been used for Pilot Balloon Observations in India, e.g., balloon made of gutta percha tissue made at the Upper Air Observatory at Agra/Delhi, balloons from rubber tissues obtained from Germany, and rubber balloons obtained from England, Germany or America. The size of the balloon used varied with the season, bigger ones being invariably used for unrestricted ascents in clear weather.

The method of observation and computation throughout was the single station 'tail method'. The length of tail used depended upon the weather and the size of the balloon, 100 metre tails with flags at $12\frac{1}{2}$, 25, 50 and 100 metres being normally used with the bigger size balloons in clear weather.

Most of the flights were checked by the Central Observatory at Agra/Delhi before accepting them. In deciding the height up to which a particular flight is accepted, the shape and character of the 'height line' is particularly examined along with the other factors.

It can be remarked that these high level winds obtained from Pilot Balloon Observations depict the conditions during clear weather only. However, with the design of instruments for determining the upper winds by Radio, it will be possible to obtain high level data in larger numbers in all seasons. Though the present analysis may not represent the circulation over disturbed areas, it will be a fair representation of the general circulation over the country. The upper winds over a particular area during cloudy season can be inferred by extrapolation, e.g., even if no ascents are possible on the western half of the Peninsula during the monsoon, high ascents are possible on the eastern half, and the winds at these high levels can be fairly representative of that over the West Coast.

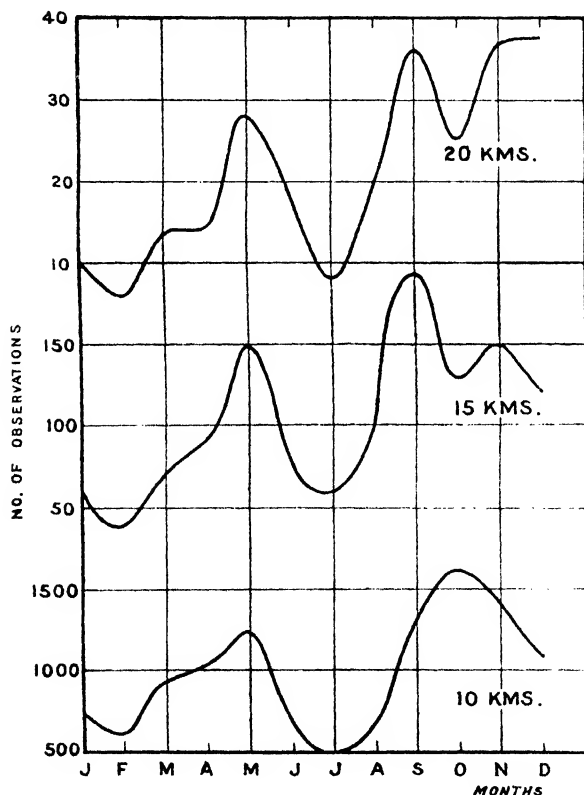


FIG. 1. TOTAL NO. OF OBSERVATIONS AT 10, 15 & 20 KMS OVER INDIA IN DIFFERENT MONTHS.

Fig. 1 gives the total number of observations over the whole of India and its neighbourhood during each month for the 10, 15 and 20 km. level. The number of

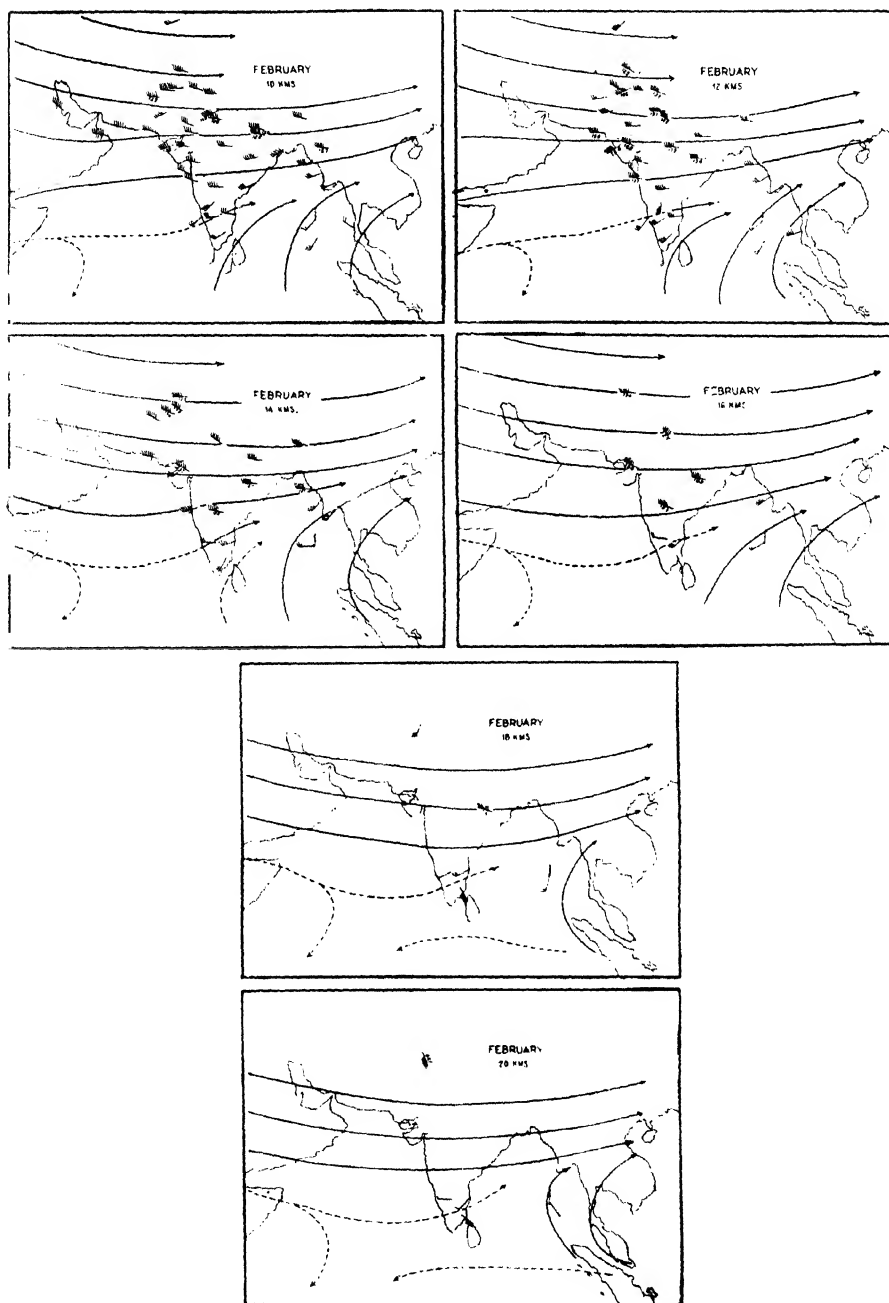


FIG. 2.

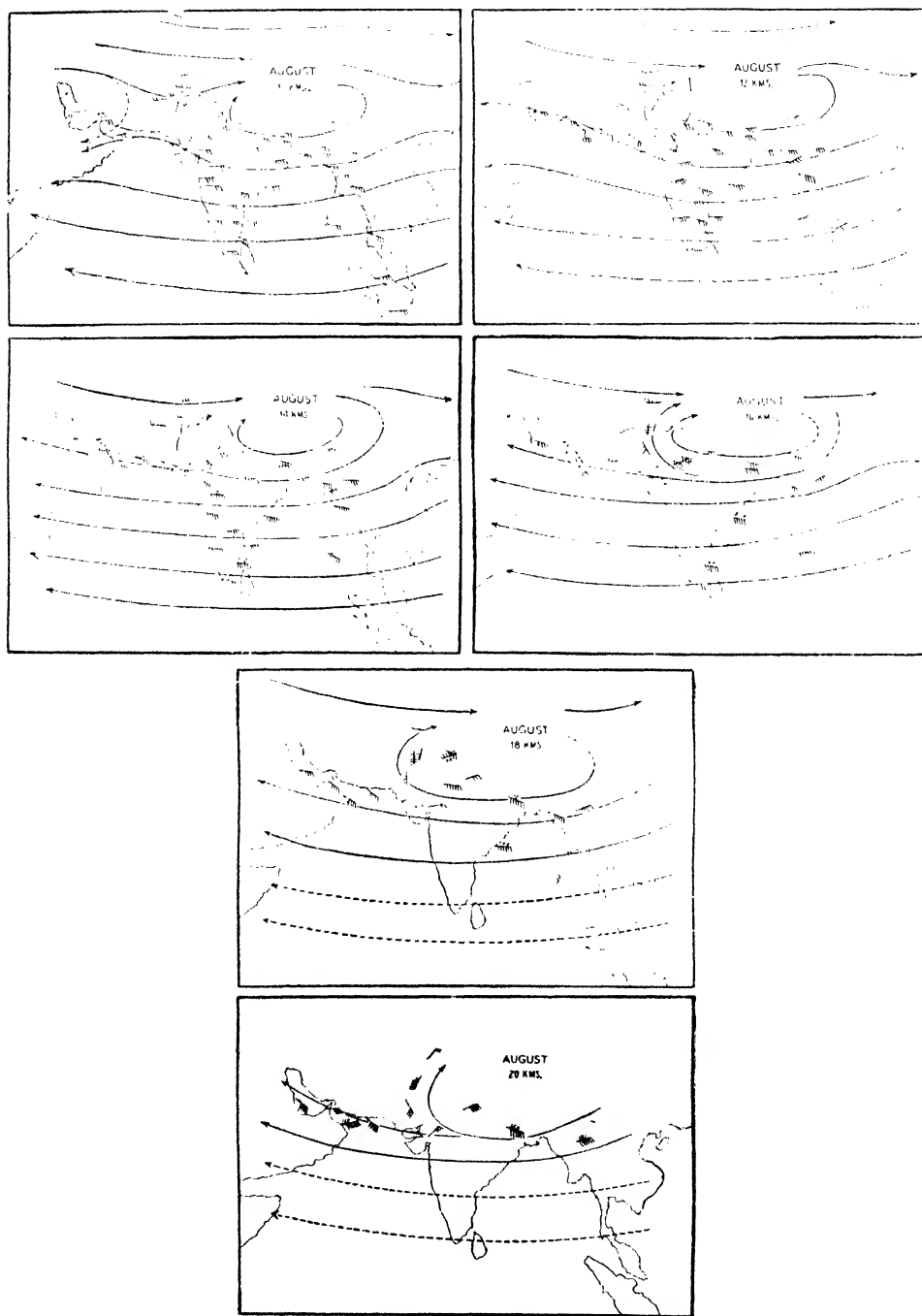


FIG. 3

observations shows minima in the two months February and July. The comparatively small number of observations during February can be explained as being due to the winds being strong and from the west over the country at most of the levels with the result that the balloons are lost at low angles to the east before long.

The comparatively fewer observations during the month of July can be easily explained as due to the south-west monsoon when most of the country is cloudy.

During the months, February to May, though there is no large change in the direction of winds, the wind speeds decrease from month to month, particularly over northern India below the 10 km. level. Therefore the balloons do not drift horizontally to low angles so quickly in May as in February, and the number of high observations are also larger. There is a sudden drop in the number of observations after this month due to the onset of the monsoon.

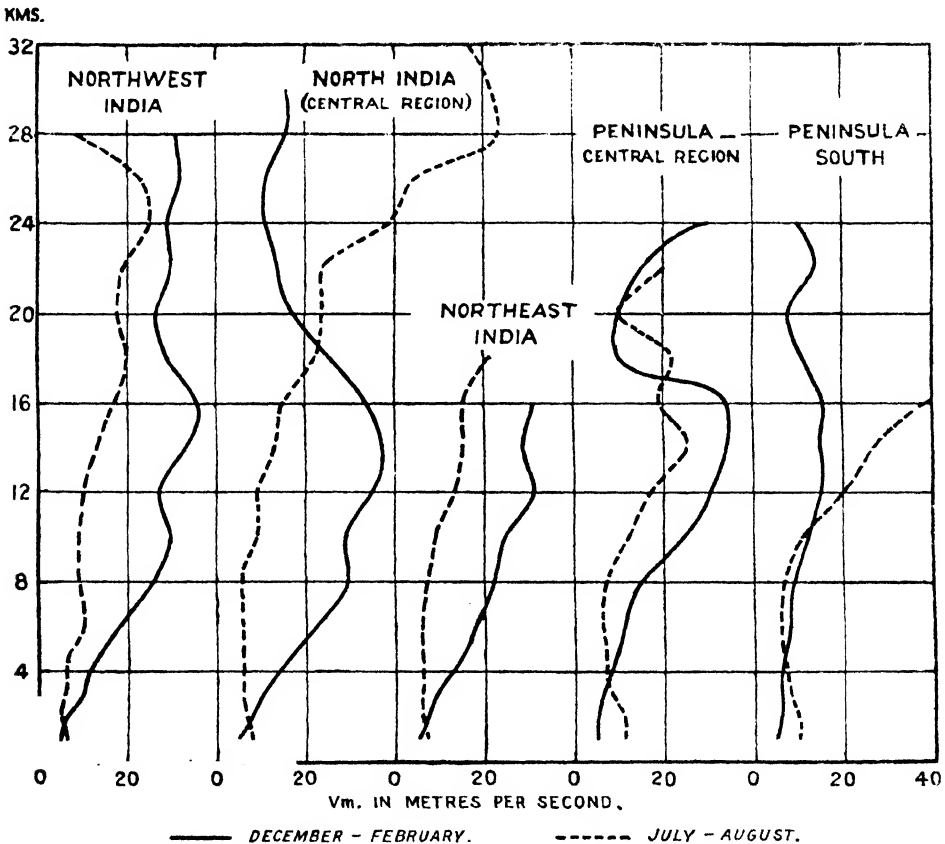


FIG. 4. MEAN WIND OVER DIFFERENT REGIONS IN INDIA.

The second maximum during September and October is also due to the clearing of the skies after the monsoon; the number of observations are greater in September at the 15 and 20 km. levels, as the winds are weaker during this month than during October at most levels over northern India.

All available data were analysed and the resultant direction and velocity of winds were charted for the levels 10, 12, 14, 16, 18 and 20 kms. for different months. Lines showing the general direction of flow of winds were also drawn.

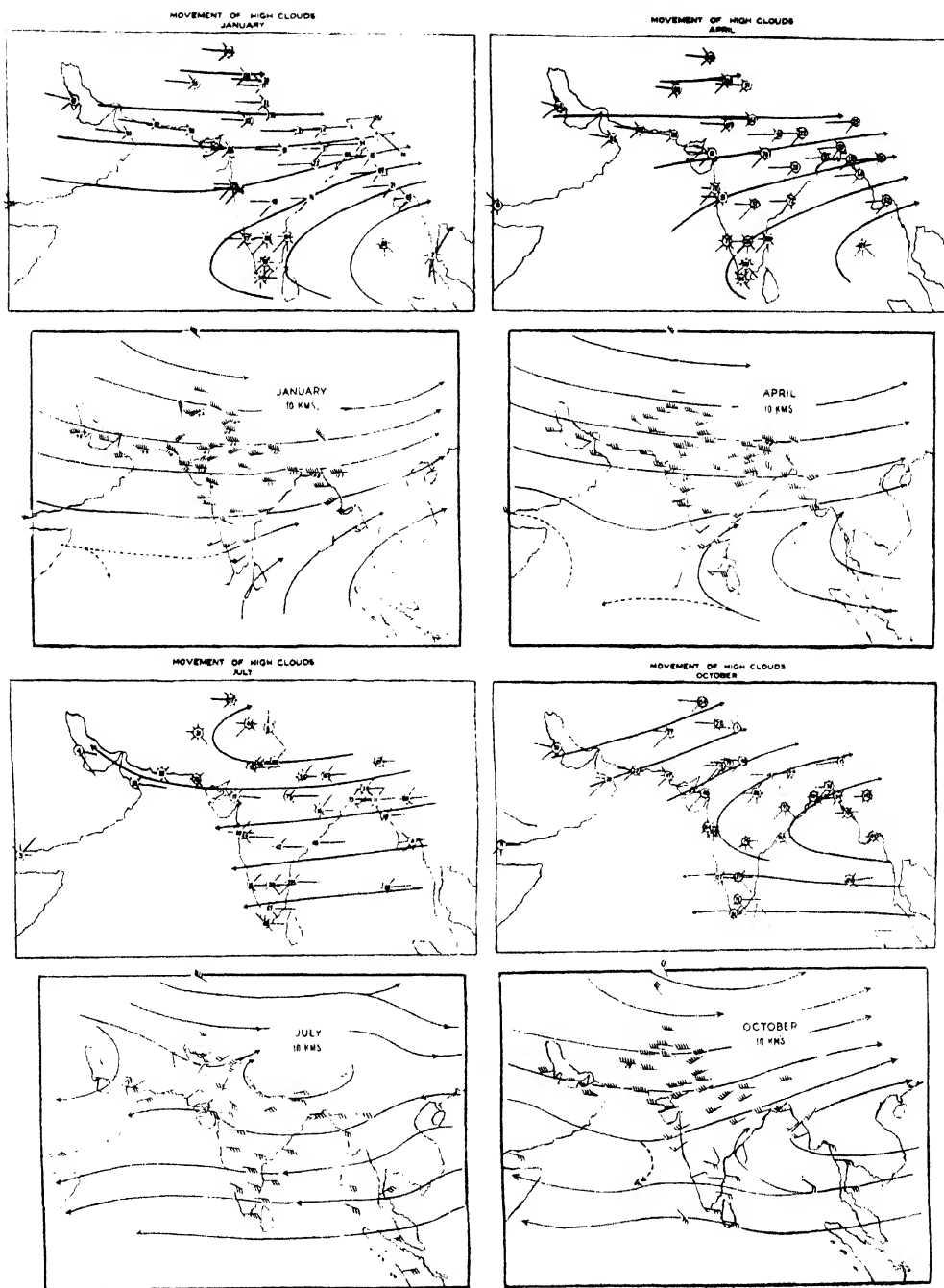


FIG.5

Figs. (2) and (3) are the charts for the two months February and August. The 'High' circulation over south China Seas observed during the winter month of February moves to the north from month to month till August when it is situated over the Himalayas. It gradually moves back to the South China Seas from September onwards. The winds at all levels are, therefore, westerly over India and its neighbourhood during winter. But during the monsoon up to 20 kms. they are mostly easterly except at the extreme north as indicated by the winds at Peshawar. At Peshawar, the winds are westerly in all the months from 10 to 20 kms. However, the single available observation for August shows that the wind at 20 kms. and above is easterly up to the 29 km. level and has an average speed of about 45 km. per hour.

The variation of the mean speed of wind at different heights over the different regions of India during the winter and monsoon is shown in Fig. 4. During winter, the winds are stronger over the northern half of the country, and attain their largest speed between the levels 12 and 16 kms. Over this area, velocities of the order of 150 to 200 km. per hour are common during this season. Above the 16 km. level, there is an appreciable decrease of speed with height. In the southern half of the Peninsula, the speed between the 10 and 20 km. level averages about 45 kms. per hour.

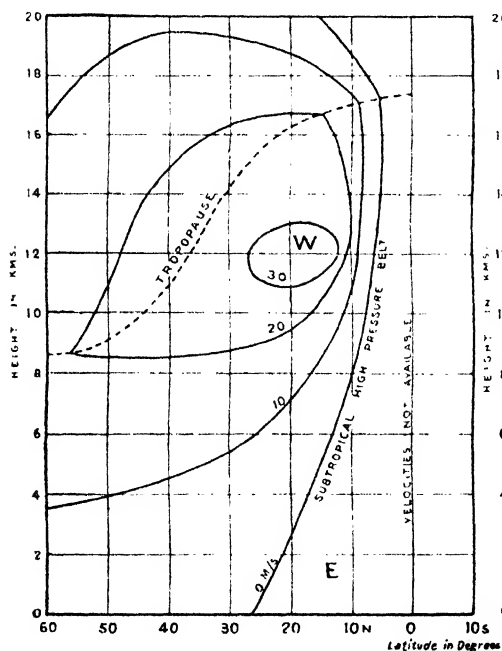


FIG. 6(a). ZONAL COMPONENTS OF GRADIENT WINDS. FEBRUARY. (BJERKNES)

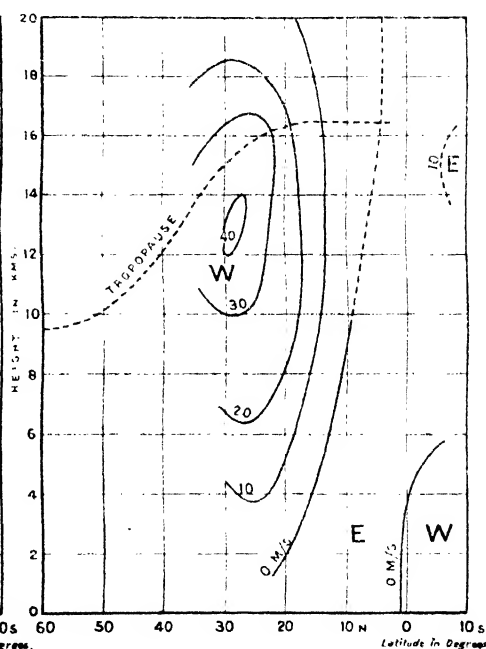


FIG. 6(b). E-W COMPONENTS OF WINDS ALONG 78°E (DEC.-FEB.)

During the monsoon, winds over northern India are weaker than those during winter; in the southern half of the Peninsula, they are stronger than those during December-February; but information is not available above the 16 km. level over this area. However, even in these levels, easterly winds of the order of 100 to 150 kms. per hour appear to be common.

Ramanathan and Ramakrishnan (1939) have summarized and published charts showing the direction of movement of high clouds over India and neighbourhood in

January, April, July and October. The wind circulation at the 10 and 12 km. level agrees fairly accurately with the movement of the high clouds. (Fig. 5.) One can, therefore, infer that the high cloud level over India is of the order of 10–12 kms. where the temperature is about 220°A .

From the upper air pressure and temperature distribution, Bjerknes (1933) has calculated the zonal strength of the gradient winds for different heights during the two months February and August—Fig. 6(a) and Fig. 7(a). In these diagrams Bjerknes has drawn the boundary between the westerly and easterly components below the 10 km. level in the tropics from the observations of Banerji and Ramanathan (1930).

The mean west-east components of winds up to 20 kms. over the 78°E . longitude were calculated and charted for the two seasons, December–February and July–August, Figs. 6(b) and 7(b). The diagrams represent the zonal circulation over the region from the equator to about 35°N . as upper wind data are available only for this region. The data up to 8 kms. have been taken from Ramanathan and Ramakrishnan's paper. The upper wind observations of Batavia (1943) have also been incorporated and the curves for regions to the south of 5°N . latitude are therefore approximate to this extent. The height of the tropopause is from Ramanathan's diagram. The zonal circulation calculated by Bjerknes agrees fairly accurately over the region for which the observations are available.

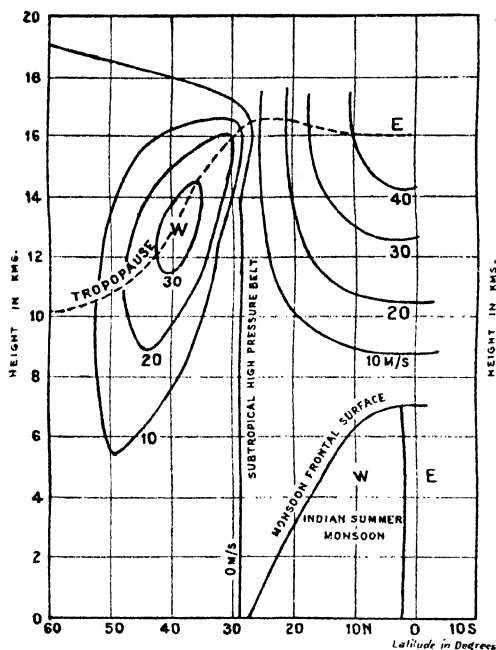


FIG. 7(a) ZONAL COMPONENTS OF GRADIENT WINDS
AUGUST (BJERKNES)

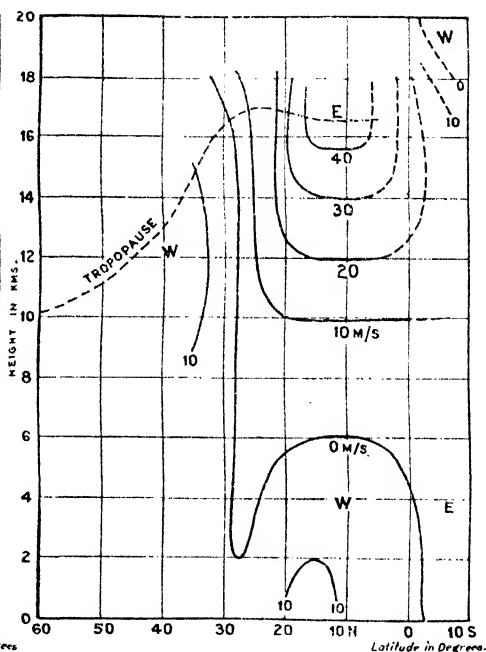


FIG. 7(b). E-W COMPONENTS OF WINDS
ALONG 78°E (JULY-AUGUST)

This is in brief the general circulation of winds at high levels over India and its neighbourhood. A more detailed paper on the subject is under preparation.

REFERENCE.

- Banerji, H. C. and Ramanathan, K. R. (1930). Upper air circulation over India and its neighbourhood up to the cirrus level during the winter and the monsoon. *Sc. Notes, India Met. Dept.*, **3**, No. 21.
- Bjerknes, V., Bjerknes, J., Solberg, H. and Bergeron, T. (1933). *Physikalische Hydrodynamik*, 648-653.
- Climatic Charts of India and Neighbourhood for Meteorologists and Airmen (1943).
- Ramanathan, K. R. and Ramakrishnan, K. P. (1939). The General circulation of the Atmosphere over India and its Neighbourhood. *Memoirs India, Met. Dept.*, **26**, Pt. X.
- Sur, N. K. (1930). Winds in higher levels over Agra. *Sc. Notes, India Met. Dept.*, **2**, No. 15.

ON THE NEPHRIDIA AND COELOMODUCTS OF SERPULIMORPHA AND CIRRATULIDAE.

By G. KRISHNAN, M.A., M.Sc., Department of Zoology, Presidency College,
Madras.

(Communicated by Prof. H. K. Mookerjee, D.Sc. (Lond.), D.I.C., F.N.I.)

(Received April 26, 1948 ; read March 4, 1949.)

CONTENTS.

	Page
I. INTRODUCTION	29
II. MATERIAL AND METHODS	29
III. PREVIOUS WORK	30
IV. NEPHRIDIA AND COELOMODUCTS OF—	
(a) <i>Dasychone cingulata</i> Grube	30
(b) <i>Mercierella enigmatica</i> Fauvel	31
(c) <i>Sabellaria spinulosa</i> Leuckart	33
(d) <i>Audouinia anchylochaeta</i> Schmarda	35
V. DISCUSSION	35
VI. SUMMARY	37
VII. REFERENCES	38

I. INTRODUCTION.

Goodrich (1900, 1945) gave a new orientation to the study of nephridia and genital ducts, particularly in the Annelida. Since the publication of Goodrich's work, there have been, however, very few investigations in this field, and there are still some problems that require elucidation. Our knowledge of the thoracic organs of the Serpulimorpha is incomplete, especially in regard to their form and structure. Besides the thoracic organs, paired segmental organs with wide funnels are noticed in the abdomen and in some instances in the thorax also (Evenkamp, 1931), but their homology and relation to the thoracic organs are uncertain.

The present paper is a study of the morphology of the thoracic organs and also of the posterior segmental organs in the different species of the Serpulimorpha. A study of the segmental organs of the Cirratulidae is also included, as they recall to some extent features noticed in the Serpulimorpha. The segmental organs of the Cirratulidae have an additional interest. In the Cirratulid *Dodecaceria concharum* (= *Dodecaria concharum*), the posterior segmental organs, as shown by Caullery and Mesnil (1898), are formed entirely from the coelomic epithelium and are independent of the nephridial component. Such a condition is of rare occurrence in the Polychaeta and warrants a detailed study.

II. MATERIAL AND METHODS.

The specimens studied in the present investigation are (1) *Dasychone cingulata* Grube, *Mercierella enigmatica* Fauvel, *Sabellaria spinulosa* Leuckart and the Cirratulid *Audouinia anchylochaeta* Schmarda. Specimens of *Dasychone cingulata* were

obtained from Madras harbour, where they are found in abundance on the boulders. *Mercierella enigmatica* was obtained from the Ennore backwaters near Madras. It lives in calcareous tubes which are coiled at the base and attached to the oyster shells. *Sabellaria spinulosa* was obtained in a collection of specimens dredged from the sea near Madras. *Audouinia anchylochaeta* was obtained in large numbers in the Madras harbour.

The worms were narcotized by treatment with an 8% solution of magnesium chloride. The narcotized worms were dropped into the fixative and immediately afterwards cut into small pieces. Bouin's fluid, Bouin Duboscq, and Susa's fluid gave the best results. The sections were cut 8μ to 12μ thick and stained in Heidenhain's iron haematoxylin and counterstained with eosin.

III. PREVIOUS WORK.

Among the earlier zoologists Clapar  d   (1873), Haswell (1884) and Meyer (1887) investigated the nephridial system of the Serpulimorpha and described the thoracic organs and the abdominal segmental organs as well. But to Goodrich (1900), belongs the credit of demonstrating that the nephridia of the Serpulimorpha are of the mixonephridial type and that the internal ciliated funnels are of the nature of coelomostomes. More recently Evenkamp (1931) described in detail the thoracic organs and the posterior segmental organs in the Sabellid worms *Euchone papillosa* and *Laonome kroyeri* and showed that they were remarkable in having a net-like formation in the thoracic region and in the occurrence of segmental organs functioning as gonoducts. The investigations of Thomas (1940) and Segrove (1941) support in general the conclusions of the earlier authors. Meyer (1887) observed that the thoracic organs in *Sabellaria alveolata* resemble those of the Sabellidae and Serpulidae, and open to the exterior by a common median duct. But according to Dehorne (1908) the thoracic organ of *Sabellaria alveolata* is independent of its fellow and opens by a separate dorsolaterally situated nephridiopore. Dehorne (1908) has pointed out the resemblance between the thoracic organs of the Sabellaridae and the anterior nephridia of the Cirratulidae. The nephridia of the Cirratulidae were described by Clappar  d   (1869), Cosmovice (1879) and Cunningham (1887). Caullery and Mesnil (1898) observed that in *Dodecaceria concharum*, besides the anterior nephridia there are segmental organs with large funnels which develop late during the epitokous phase from the coelomic epithelium and serve for the exit of the genital products. In the atokous forms such structures are absent. According to Goodrich (1900) the anterior pair of nephridia and the posterior segmental organs are of the nature of mixonephridia, with the nephridial portion predominant in the anterior pair, but reduced in the posterior segmental organs which are characterized by prominent coelomostomes.

IV. NEPHRIDIA AND COELOMODUCTS.

(a) *Dasychone cingulata* :

The nephridial system in *Dasychone cingulata* consists of an anterior pair of thoracic organs and a series of large-funnelled segmental organs occurring both in the thorax and abdomen. On dissecting the worms, the thoracic organs are seen as thin-walled, much lobulated and sac-like structures, situated on either side of the oesophagus and extending through the first six or seven segments of the thorax (Fig. 1a). The thoracic organ belongs to the first thoracic segment and consists of four parts :—First the ciliated funnel which extends into the head segment and reaches a point close to the brain and immediately behind a band of muscles of the head segment (Fig. 1b). The funnel is asymmetrical and its position is similar to that found in the Serpulid *Psymnobranchus protensus*. It is lined with flattened and

prominently ciliated epithelium. The cytoplasm stains homogeneously and the cell-limits are not distinct, the nuclei occurring at intervals along the margin of the funnel. Succeeding the funnel, is a narrow canal which forms the beginning of the descending limb of the thoracic organ (Fig. 1c and Ph.m. 1). It runs backwards and gradually widens. The wall of the canal is formed of a single layer of columnar cells with rounded nuclei and a number of chromatin bodies. The cytoplasm is granular, showing dark-staining bodies, probably of excretory nature. The ciliation in the canal is less dense than in the funnel. The descending limb passes into a sac-like ascending limb which occupies a major portion of the space between the oesophagus and the body wall (Fig. 1c and Ph.m. 1). The walls of the ascending limb are folded inwards and the folds present an irregular net-like appearance in sections. The epithelium lining the ascending limb is composed of much flattened cells, with vacuolated cytoplasm and long flagelliform cilia, not unlike those in the glandular sac of the thoracic organs of *Eupomatus elegans* (Haswell, 1884). The beat of the cilia in the canals appears to be reversible, and it is possible that the current of water flows in both directions in the canals. The ascending limb passes anteriorly into a narrow duct which runs at first laterally, and then dorsally to the corresponding part of the opposite side, with which it unites to form a median duct. The median duct runs dorsal to the brain and opens to the exterior at the base of the branchiae. The terminal part of the duct is short and is lined with flattened cells. A thin coelomic epithelium covers the outer surface of the thoracic organ in the different regions.

The segmental organs are paired and provided with large funnels and short ducts. They occur in the thorax from the second thoracic segment onwards along with the thoracic organs, and also in all the abdominal segments. The form, structure and position of the segmental organs differ from those of the thoracic organs. Each segmental organ lies ventrolaterally close to the septum and opens into the coelom by a large funnel ventral to the dorsal longitudinal muscles. The greater part of the segmental organ is formed by the funnel which narrows into a short canal opening to the exterior ventrally to the parapodium. The funnel and the duct lie in one and the same segment. The lining of the funnel is composed of cubical ciliated cells having oval, or rounded nuclei with prominent nucleoli and chromatin. The cytoplasm of the cells stains uniformly and there are no excretory granules. The cilia are densely arranged and arise from basal granules arranged in a row in the cell bodies (Fig. 1e). A fold of connective tissue extends from the septum and supports the outer wall of the funnel on the side adjacent to the septum. The lining of the duct does not present any special features. The duct may be regarded as a continuation of the base of the funnel. In some cases the genital products were noticed in their passage to the exterior through the funnel and duct.

(b) *Mercierella enigmatica* :

Mercierella enigmatica agrees with other Serpulids in having the thoracic nephridia reduced to a single anterior pair situated in the first setigerous segment. Each thoracic organ consists of a narrow ciliated funnel leading into a U-shaped tube, the ascending limb of which joins its fellow of the opposite side to form a median tube opening to the exterior at the anterior end. The funnel (Fig. 1f) is V-shaped in sections with thin walls, the cells of which are much flattened and thickly ciliated. The funnel is continued into a narrow canal which gradually widens out into a sac-like structure forming the ascending limb of the organ (Fig. 1f). The walls of this sac-like expansion are composed of columnar ciliated cells. The cilia are long and flagelliform, similar to those described in the ascending limb of *Dasychone Cingulata*. Accumulations of dark-staining granules, probably of an excretory nature, are found in the cells. Externally the sac is covered by a thick fibrous coat. In front, the sac narrows into a duct which joins

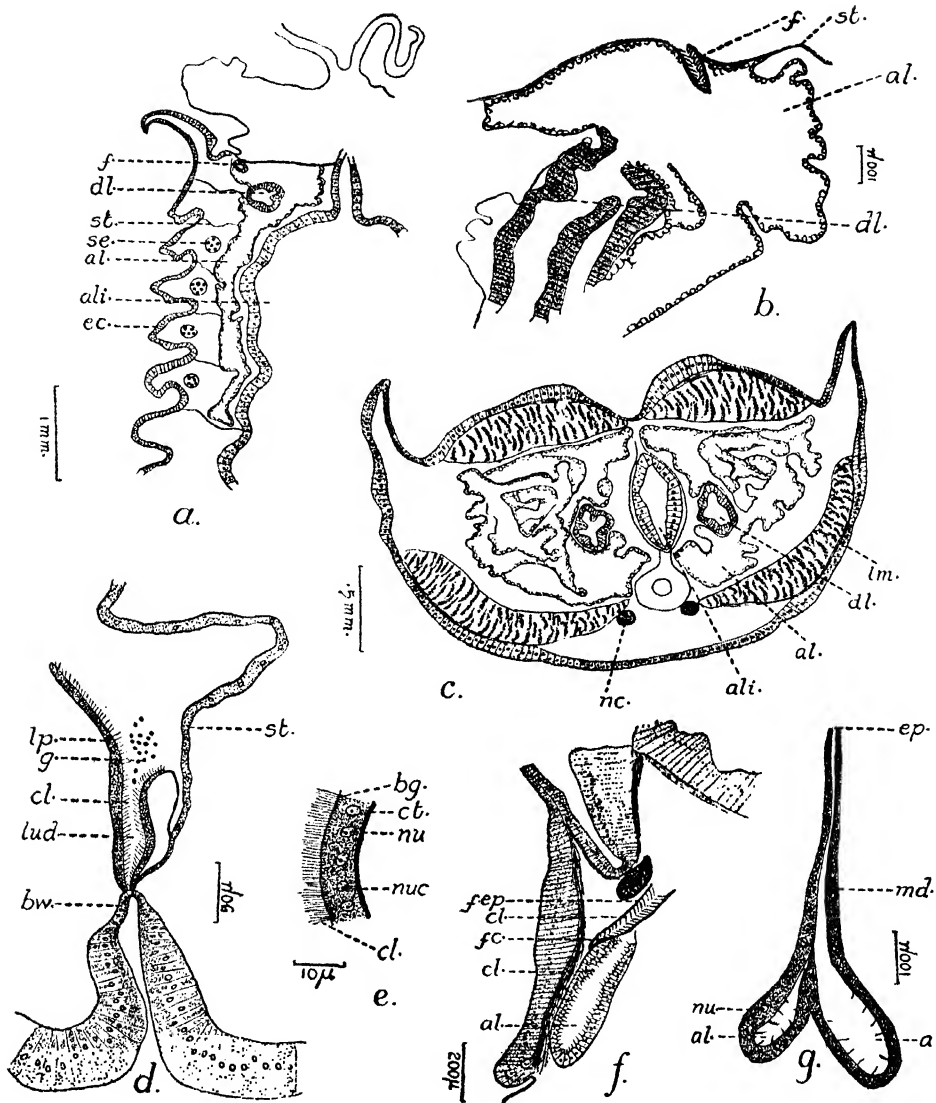


FIG. 1.

All figures have been drawn with camera lucida.

Dasychone cingulata :

- a. Thoracic organ of *Dasychone cingulata* as seen in a horizontal section of the anterior end of the worm.
- b. The ciliated funnel of the thoracic organ as seen in a horizontal section of the worm.
- c. Transverse section of the worm passing through the thoracic organs. Both the descending and the ascending limbs of the organ are seen in the section.
- d. Gonoduct of the thorax as seen in a horizontal section of the worm.
- e. A portion of the wall of the gonoduct.

Mercierella enigmatica :

- f. Longitudinal section of the ciliated internal funnel of the thoracic organ.
- g. The terminal portion of the thoracic organs of either side which join together to form a common duct as seen in horizontal sections of the worm.

(Key to lettering—see page 39.)

with its fellow of the opposite side to form a median duct (Fig. 1g), leading to the exterior. The lining of this canal is composed of flattened cells, having a few cilia and without excretory granules or other special inclusions.

The paired segmental organs which function as gonoducts are confined to the abdomen and do not extend into the thoracic segments. The most prominent part in each segmental organ is a large trumpet-shaped funnel opening ventrolaterally, above the ventral bundle of longitudinal muscles (Fig. 2a). The lips of the funnel are unequal and composed of cubical cells with long cilia, and without any special inclusions. The funnel is continued into a duct which loops round the longitudinal muscles and passes to the external pore (Ph.m. 2) which is situated ventrally, and somewhat towards the median line. The lining of the duct is similar to that of the funnel. Genital products are sometimes found in the duct. The external aperture is closed by a thin membrane which is probably ruptured by the accumulation of the genital cells at the aperture, as has been recorded in the case of the Sabellids, *Launome kroyeri* and *Euchone papillosa* (Evenkamp, 1931). The general structure and disposition of the segmental organs recall those of *Pomatoceros triqueter* (Thomas, 1940).

(c) *Sabellaria spinulosa* :

The general lay-out of the nephridial system of *Sabellaria spinulosa* resembles that of the Sabellids and Serpulids. The thoracic organs are formed in the first three segments of the thorax, lying on either side of the oesophagus. They form U-shaped loops, the outer limbs of which are short, narrow, and lie in close proximity to the body wall, while the inner limbs are expanded into wide sac-like structures (Fig. 2b). The outer limb opens into the coelome by a ciliated funnel with unequal lips which is situated at the dorso-lateral border of the segment, close to the longitudinal muscles. The funnel is lined with flattened cells bearing long cilia and leads into a narrow canal which forms the commencement of the descending limb. The cells lining the descending limb are narrow, with rounded nuclei and granular cytoplasm and bear a sparse coating of cilia. The ascending limb, which forms the inner loop of the thoracic organ, expands into three superposed sac-like structures closely surrounding the oesophagus (ph.m. 3). The cells lining the sacs are characteristically vacuolated and possess basally situated nuclei. The sacs of the two sides in each pair remain separate anteriorly, and end blindly. There is no median duct as is seen in the thoracic organ of Sabellids and Serpulids. Posteriorly, the dorsal sacs of the thoracic organ appear to open into each other, dorsal to the oesophagus. Dehorne (1908) regarded the external opening of the thoracic organs to be situated above the parapodia of the second segment. My observations fail to confirm the presence of any such external opening. A careful study of the sections shows that a lateral extension of the thoracic organ enters the parapodial cavity of the second segment and reaches the branchia where it ends blindly (Ph.m. 3). Anteriorly also there is no evidence of a common median duct leading to the exterior. The close association of the sac-like expansions of the ascending limb with the oesophagus in this species seems significant. The walls of the sac and the oesophagus are thin and it is possible that they allow diffusion of substances into the lumen of the oesophagus. The absence of a definite external pore would lend additional support to this view. The absence of a common median duct may be explained as a secondary reduction. Paired segmental organs occur in all segments behind the 8th segment. The funnel is wide and the duct connected with it is short (Fig. 2c). The opening of the funnel lies ventrolaterally below the parapodia. Both the funnel and the duct lie in the same segment. The epithelium of the funnel as well as the duct is composed of a single layer of cells possessing a dense covering of long cilia, and a uniformly staining cytoplasm with found nuclei. There is no histological difference between the funnel and duct.

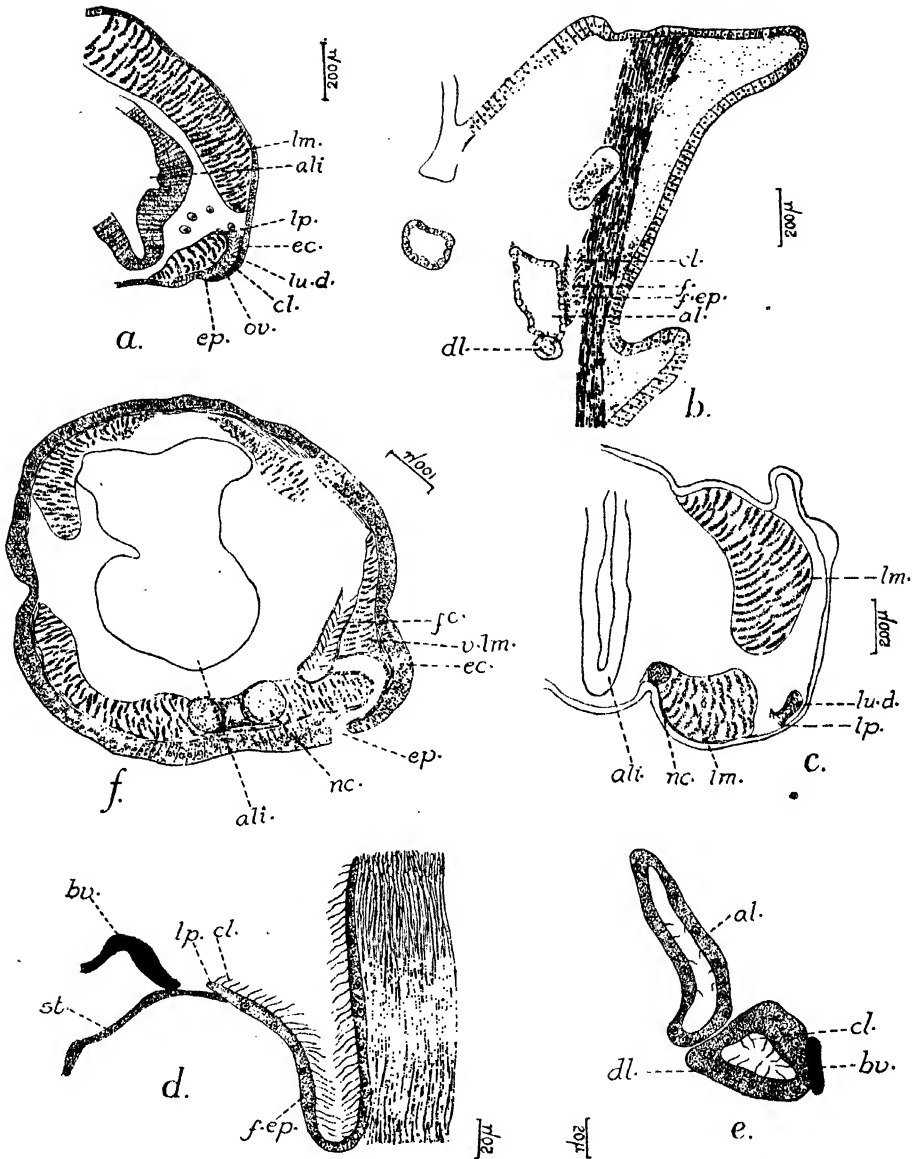


FIG. 2.

All figures have been drawn with camera lucida.

Mercierella enigmatica: a. Abdominal segmental organs which serve as gonoducts as seen in a transverse section of the worm passing through the abdominal region.

Sabellaria spinulosa: b. Longitudinal section of the internal ciliated funnel of the thoracic organ. c. The posterior segmental organ of the abdomen as seen in a transverse section of the worm.

Audouinia anchylochaeta: d. A longitudinal section of the internal ciliated funnel of the anterior nephridium. e. A section of the ascending and descending limbs of the anterior nephridium. f. The terminal part of the nephridial canal and the nephridiopore which lies ventrolaterally as seen in a transverse section of the worm at its anterior end.

(Key to lettering—see page 39)

(d) *Audouinia anchylochaeta* :

The nephridia in this species are reduced to a single anterior pair situated in the first two setigerous segments. There are no other segmental organs. Each nephridium is in the form of a slender U-shaped structure, with the two limbs closely applied to each other. The funnel of the nephridium, which is provided with unequal lips and a dense coat of cilia, lies in front of the septum between the second achaetous segment and first setigerous segment (Fig. 2d), and opens into the coelom in the former segment. The epithelium lining the funnel is thin and formed of a single layer of ciliated cells. The cell limits are not clearly defined, and the nuclei are found at intervals. The cilia are long and prominent in the region of the funnel but gradually become short as the funnel passes into the descending limb which has an almost straight course as it passes backwards. It is lined by cubical ciliated cells, with prominent round nuclei and cytoplasm showing a number of concretions which stain dark in iron haematoxylin. The cilia are few and in the more distal parts of the limb they are fewer still. The descending limb of the nephridium extends behind into the second setigerous segment where it turns forwards, forming a bend which leads to the ascending limb. The cells of the limb are flat, but otherwise similar to those of the descending limb. Near the anterior septum of the first setigerous segment, the ascending limb bends abruptly at a right angle and curves to the ventral wall of the body where it opens to the exterior by the nephridiophore (Fig. 2f and Ph.m. 4). The walls of the terminal part of the nephridial canal from the point of its curvature from the main body are very thin, and the cells much flattened, with small nuclei and reduced cilia. The nephridiophore is a small oval aperture in the ventral epidermis, close to the ventral longitudinal muscles (Fig. 2f and Ph.m. 4). A thin, coelomic epithelium with oval nuclei covers the nephridium.

In segments other than the first two setigerous segments, no trace of segmental organ is found. In mature specimens the posterior segmental compartments, from the twelfth segment backwards, are filled with reproductive elements but there are no gonoducts for their liberation to the exterior.

V. DISCUSSION.

A comparison of the thoracic organs in *Dasychone cingulata*, which are described in this paper, with those of other Sabellids shows that they bear no resemblance to any one particular type. In their extension into a greater part of the thorax, they resemble those of *Spirographis spallanzanii*, and in the expansion of the outer loop to form a sac-like structure they resemble those of *Euchone papillosa*, and in the position of the funnel they resemble those of the Serpulid *Psygmodranchus protensus*. The thoracic organs of the Sabellidae show a variety of form and structure. In the Serpulidae the thoracic organs show a wider range of variation, and two distinct types have been described:—(1) In forms like *Psygmodranchus protensus* the thoracic organ is typically U-shaped with an open internal funnel and common median duct at the anterior end, and (2) in forms like *Eupomatus elegans* (Haswell, 1884) and *Filograna implexa* (Faulkner, 1930) the thoracic organs are not U-shaped, but are sac-like structures continued on each side into a duct which joins its fellow to form a median canal leading to the external pore. The absence of the descending limb and the position of the funnel in the case of the second type are other differences. In other respects the two types are quite similar. It is probable that the second type is derived from the U-shaped thoracic organ of the first type by the suppression of the descending limb. With regard to the thoracic organs of the Sabellaridae, there has been much uncertainty. Meyer's view is that the thoracic organs of Sabellaria agree in all respects with those of the Sabellidae and Serpulidae, but this view is untenable in the light of the work of Dehorne (1908). The observations

made in this paper show that the thoracic organs of *Sabellaria* differ from those of the Sabellidae and Serpulidae.

The anterior nephridia of *Audouinia anchylochaeta* are similar to the type described in other species of Cirratulidae in all essential features. They resemble the thoracic organs of the Serpulimorpha in being restricted to a single pair, in their U-shaped form, and in the position and structure of the internal ciliated funnel. But they differ from the nephridia of Cirratulidae in the nature and position of the external opening, a feature which Dehorne (1908) emphasized as indicating an affinity with the Sabellaridae.

The anterior nephridia of *Audouinia* are very much like the nephridia of *Scalibregma inflatum* Ashworth (1902). In both, the nephridium is U-shaped opening into the coelom by a small pre-septal funnel leading to the nephridial loop which opens to the exterior by the nephridiophore situated in the segment just behind the one in which the funnel opens. But unlike the arrangement in *Scalibregma*, where the nephridia are arranged in segmental pairs numbering about 40, a single pair is found in *Audouinia* although in other Cirratulidae the nephridia occur in the posterior segments also. These posterior nephridia differ, however, from the anterior pair in possessing larger funnels and shorter ducts. This difference may be explained as due to the specialization of the posterior nephridia for an exclusively reproductive function (Goodrich, 1900).

Goodrich (1900, 1945) pointed out that the thoracic organs are homologous with the mixonephridia, but it is not known in many instances whether the mixonephridium is formed from a metanephridium or a protonephridium. Faulkner (1930) observed that the thoracic organs of *Filograna implexa* are metanephridial like those of Nereidae and Capitellidae, while according to Malaquin (1908), they are protonephridial. The morphological evidence based on the study of the adult animals alone is insufficient for the determination of the homology of the nephridial system, but a comparison of the arrangement of the nephridial system in *Poecilochaetus serpens* (Allen, 1904) with that in the Serpulimorpha and Cirratulidae, suggests that the thoracic organs are metanephridial. In *Poecilochaetus*, the nephridia occur in most of the body segments, and are metanephridial in the anterior segments, till the sixteenth segment, and mixonephridial in the posterior segments. This arrangement represents a generalized condition from which the more specialized types found in the Serpulimorpha and Cirratulidae could be derived. The arrangement found in *Dasychone cingulata* resembles to some extent that occurring in *Poecilochaetus*, as the thoracic organs belonging to the first segment and the gonoducts occurring in the second segment onwards form a complete segmental series with the thoracic organs specialized for an excretory function and the remaining for a genital function. The absence of segmental organs in the thorax functioning as gonoducts in the other species of the Serpulimorpha is probably due, as suggested by Evenkamp (1931), to their degeneration consequent on the absence of genital products in the thorax. Similarly the single pair of nephridia in *Audouinia anchylochaeta* may be the last surviving representative of an originally complete series, the others having disappeared owing to loss of function. The posterior segmental organs of the Serpulimorpha are more or less uniform. The prominence of the funnel and the shortening of the duct are their characteristic features. Goodrich (1900) has pointed out that the posterior segmental organs in the Serpulimorpha are mixonephridia in which the nephridial part is reduced. A comparison of the shape and structure of the segmental organs in the different species shows that the nephridial part has been reduced in varying degrees in the different species. The condition in *Dasychone cingulata* suggests a more pronounced reduction of the nephridial part than in other species studied. If the reduction of the nephridial part is complete, the segmental organ which consists only of the coelomostome and a duct arising from it would result. This is exactly the condition described by Caullery and Mesnil (1895) in *Dodecaceria concharum*. But in this form the authors observed that the genital funnels arise

late, only during the epitokous phase, and open to the exterior to convey the genital products. The late appearance of the coelostomes is a feature not unknown in other Polychaets. Goodrich (1900) pointed out that in the Syllidae, in the immature condition, the segmental organs consist only of the metanephridia which open by nephrostomes, but in mature specimens large ciliated funnels develop and become grafted on to the nephrostome. The occurrence in *Dodecaceria* of genital funnels of the nature of coelomostomes without a nephridial component is of unusual interest from the point of view of the general theory of the relationship between the coelomoducts and nephridia. Such independently functioning coelomoducts have been recorded only in the family Capitellidae which retain the primitive relationship between these two sets of organs, while in all other families with the exception of the Nereidae in which the coelomoducts have become degenerate, these two organs are intimately associated. In *Dodecaceria concharum* genital funnels which function independently are found. This condition though apparently similar to that found in the Capitellidae is not identical with it. In the Capitellidae both coelomostomes and nephridia occur independently in every segment and function as the genital ducts and excretory organs respectively. On the other hand, in *Dodecaceria concharum*, the occurrence of the coelomostomes independently of the nephridia appears to be due to the reduction of the nephridial part in the mixonephridium, tending to a complete disappearance of the nephridial component. Such a condition, as pointed out by Goodrich (1945), is probably secondarily acquired and does not show the primitive independence between the coelomoducts and the nephridia. The segmental organs functioning as gonoducts in *Dasychone* point to their resemblance in their shape, structure and position to the genital funnels described by Caullery and Mesnil (1898). Possibly like their counterparts in *Dodecaceria*, they represent only the coelomostomes in which the nephridial part has been completely reduced.

The absence of the posterior segmental organs in *Audouinia anchylochaeta* is possibly due to the animal having a different mode of shedding the genital products. The degeneration and disappearance of the coelomoducts in correlation with the loss of their function as genital passages are known in a number of Polychaets. The condition seen in *Clistomastus* (Goodrich, 1900) is an instance illustrative of this feature. 'In *Clistomastus* where the generative cells escape through the rupturing of the body wall the genital funnels are found only in a more or less rudimentary state.' In *Audouinia anchylochaeta* it is likely that the genital products are shed by the rupture of the body wall and therefore it is probable that the genital funnels have been secondarily suppressed. A similar instance is seen in *Prionospio cirrifera* (Aiyar, 1939) in which the nephridia are reduced to three pairs at the anterior end. The absence in this species of posterior mixonephridia which are found in the allied members of the family recalls the condition seen in *Audouinia anchylochaeta*.

VI. SUMMARY.

1. The nephridia and coelomoducts of *Dasychone cingulata*, *Mercierella enigmatica*, *Sabellaria spinulosa*, and *Audouinia anchylochaeta* were studied and their morphology is discussed.

2. In *Dasychone cingulata* there is a single pair of thoracic organs. Each is U-shaped and opens internally by a ciliated funnel. The two ascending limbs of the thoracic organs join together to form a median passage opening to the exterior by a dorsal pore. A feature of the ascending limb is the sac-like expansion, whose walls have a number of ingrowths, thus presenting the appearance of a system of canals inside the sac. Segmental organs with large funnels and short ducts occur in the second thoracic segment in the thorax and in all segments of the abdomen.

3. In *Mercierella enigmatica* the thoracic organ, which is U-shaped, opens internally by a small funnel. The thoracic organs of both sides join together to form a median duct which opens dorsally. Wide-funnelled segmental organs occur in the abdominal segments, but are absent in the thorax.

4. In *Sabellaria spinulosa* the thoracic organ does not appear to possess an external opening. The ascending limb is expanded into three superposed sac-like structures which surround the

oesophagus. The descending limb and the funnel are similar to those in serpulids like *Psymobranchus protensus*.

5. In *Audouinia anchylochaeta* there is only a single pair of U-shaped nephridia opening internally by a ciliated funnel in the second achaetous segment and extending posteriorly to the second or third setigerous segment.

The external openings are situated ventro-laterally in the first setigerous segment. The posterior segmental organs are absent.

6. It is suggested that the posterior segmental organs in the different species of *Serpulimorpha* are of the nature of mixonephridia in which the nephridial part is reduced to varying degrees, while the anterior thoracic organs are probably metanephromixia.

ACKNOWLEDGMENTS.

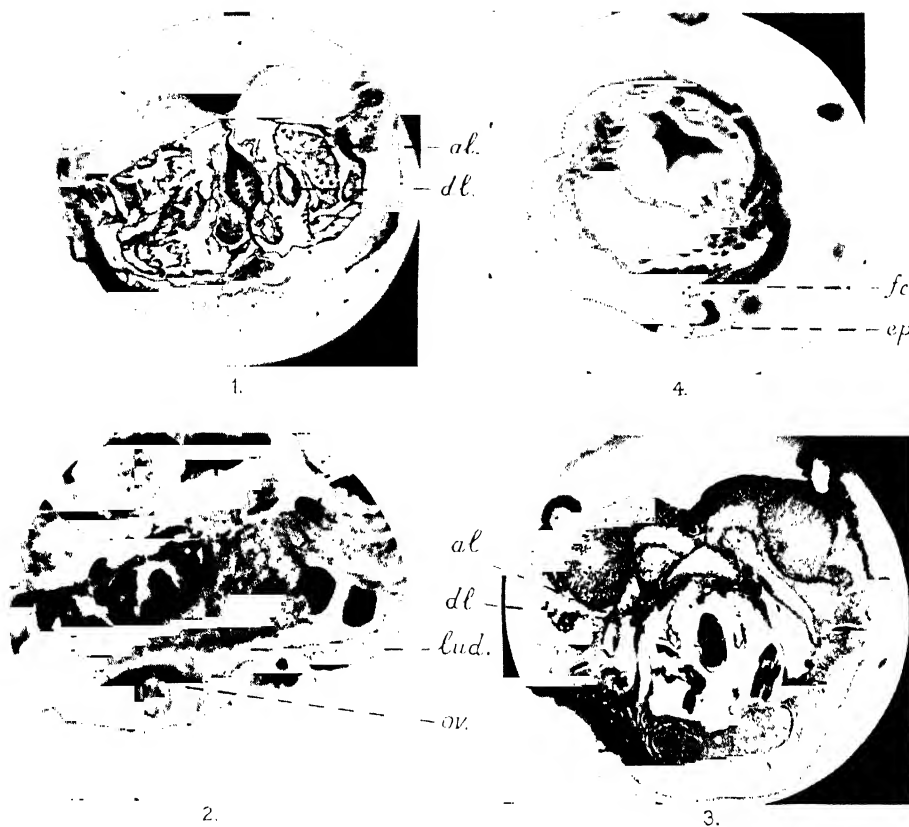
This work was carried out at the University Zoological Laboratory, Madras. I am thankful to Dr. N. K. Panikkar, formerly Director and Dr. C. P. Gnanamuthu, the present Director, for guidance and encouragement given to me. I am grateful to Dr. S. G. M. Ramanujam, formerly Principal, Presidency College, Madras, now Vice-Chancellor, Annamalai University, for help and advice received by me throughout the course of this investigation. My thanks are also due to Prof. R. Gopala Aiyar, Professor, Andhra University, for valuable suggestions and to Prof. R. V. Seshaiya of the Annamalai University, for going through the manuscript. This paper represents a part of the thesis approved for the M.Sc. degree of the University of Madras.

VII. REFERENCES.

- Aiyar, R. G. (1939). On the nephridia of *Prionospio cirrifera* Wiren. *Proc. Ind. Acad. Sci. B.*, **9**, 57.
- Allen, E. J. (1904). The Anatomy of *Pocillochaetus* Clap. *Quart. J. micr. Sci.*, **48**, 79.
- Ashworth, J. (1902). The Anatomy of *Scalibregma inflatum* Rathke. *Ibid.*, **45**, 237.
- Caullery, M. and Mesnil, F. (1898). Les formes épitoques et l'évolution des cirratulien. *Ann. Univ. de Lyon*, **39**, 1.
- Claparede, Ed. (1869). Les Annelides Chetopodes du golfe des Naples.
- (1873). Recherches sur la structure des Annelides Sedentaires. *Mem. Soc. Phys. Gen.*, **22**. (Not consulted in the original.)
- Cosmovici, L. (1879). Glandes Genitales et organes Segmentaires des Annelides Polychaetes. *Arch. Zool. Exp.*, **8**, 233.
- Cunningham, J. T. (1888). Some points in the Anatomy of Polychaeta. *Quart. J. micr. Sci.*, **28**, 239.
- Dehorne, A. (1908). Les néphridies thoraciques des Hermellides. *Comp. Rendus. Acad. Science, Paris*, **146**, 838.
- Evenkamp, H. (1931). Morphologie, Histologie und Biologie der Sabelliden species *Laonome kroyeri* and *Euchone papillosa*. *Zool. Jahrb. Abt. f. Anat.*, **53**, 405.
- Faulkner, G. H. (1930). Anat. and Histology of Bud-formation in the Serpulid *Filogramma Implexa*. *Journ. Linn. Soc. Zool.*, **37**, 109.
- Goodrich, E. S. (1900). On the Nephridia of Polychaeta, III. *Quart. J. micr. Sci.*, **43**, 699.
- (1946). Study of Nephridia and Genital ducts since 1895. *Ibid.*, **86**, 113.
- Haswell, W. A. (1884). The marine annelids of the order Serpulae. Some observations on their anatomy with the characteristics of the Australian species. *Proc. Linn. Soc. New South-wales*, **9**, 649.
- Malaquin, A. (1908). La protonéphridie des Salmaciens et Filogranes adultes. *Compt. Rend. Acad. Sci., Paris*, **147**, 699.
- Meyer, E. (1887). Studien ü.d. Körperbau der Anneliden. *Mitt. Zool. Stat. Neapel.*, **7**, 592.
- Segrove, F. (1941). The development of the Serpulid *Pomatoceros triquetor*. *Quart. J. micr. Sci.*, **82**, 467.
- Thomas, J. G. (1940). *Pomatoceros, Sabella and Amphitrite*. L.M.B.C. Memoir, No. 33.

KEY TO LETTERING.

<i>al.</i>	.. ascending limb of the thoracic organ.	<i>f.ep.</i>	.. funnel epithelium.
<i>ali.</i>	.. alimentary canal.	<i>fc.</i>	.. funnel canal.
<i>bg.</i>	.. basal granules.	<i>g.</i>	.. genital products.
<i>bv.</i>	.. blood vessel.	<i>gl.c.</i>	.. gland cells.
<i>b.w.</i>	.. body wall.	<i>lm.</i>	.. longitudinal muscles.
<i>c.ep.</i>	.. coelomic epithelium. —	<i>lp.</i>	.. lip of the funnel.
<i>cl.</i>	.. cilia.	<i>lud.</i>	.. lumen of the gonoduct.
<i>cm.</i>	.. circular muscles.	<i>md.</i>	.. median duct of the thoracic organs.
<i>ct.</i>	.. connective tissue sheath.	<i>nu.</i>	.. nucleus.
<i>dl.</i>	.. descending limb of the thoracic organ.	<i>nu.c.</i>	.. nucleolus.
<i>dl.m.</i>	.. dorsal longitudinal muscles.	<i>nc.</i>	.. nerve chord.
<i>ec.</i>	.. ectoderm.	<i>ov.</i>	.. ova.
<i>eg.</i>	.. excretory granules.	<i>st.</i>	.. septum.
<i>ep.</i>	.. external pore.	<i>se.</i>	.. setae.
<i>f.</i>	.. funnel.	<i>vo.</i>	.. vacuoles.
<i>fb.</i>	.. fibrous sheath.	<i>v.lm.</i>	.. ventral longitudinal muscles.



PHOTOMICROGRAPHS: (Ph. m.)

Dasychone caquilata

1. Transverse section of the worm showing the thoracic organs

Mercierella cingulata

2. The gonoduct in a transverse section of the worm

Salicellaria spinulosa

3. Transverse section of the worm showing the ascending and descending limbs of the thoracic organ.

Aulonimia anchylochaeta

4. The terminal part of the nephridial canal and the nephridiopore in a transverse section of the worm.

STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION— PARTS I AND II.

By AMIYA B. KAR, M.Sc., Ph.D. (Edin.), * Central Drugs and Pharmacognosy Laboratories, Government of India, Calcutta.

(Communicated by Dr. B. Mukerji, F.N.I.)

(Received October 28 ; after revision December 13; read November 25, 1949.)

PART I. ALKALINE PHOSPHATASE IN THE UROPYGIAL GLAND OF NORMAL AND OF ANDROGEN TREATED PIGEONS.

INTRODUCTION.

Selye (1943) observed that the uropygial gland in the fowl depressed under the influence of testoid compounds. Kar (1947) made an extensive study of the relation of sex hormones to this sebaceous type of gland in the fowl. He showed that castration produced atrophic changes in the gland which, however, were prevented by replacement therapy with testosterone propionate. He further noted that testosterone depressed the uropygial gland of normal cockerels, but estrogen treatment failed to influence this gland. This ineffectiveness of estrogen was explained by the assumption that the female sex hormone failed to influence the uropygial gland of fowls with functioning testes. Recently, the validity of this assumption was tested by Kar (1949) with female Indian spotted munia, *Uroloncha punctulata* (L.) as the experimental material. It was noted that estrogen treatment stimulated the uropygial gland of this passerine species and thereby indicated the sex-specific nature of action of this hormone on the gland.

Montagna and Hamilton (1947) demonstrated that diffuse quantities of alkaline phosphatase were present in the sebaceous cells and the sebum of the golden hamster. In the glands of the ovariectomized female the enzyme was absent, but it was restored on androgen therapy. Since the uropygial gland in birds resembled the mammalian sebaceous glands both microscopically and physiologically, it seemed desirable first to study the location and distribution of alkaline phosphatase in this gland, and secondly to determine the effects of androgenic treatments on phosphatase activity in this sebaceous type of gland.

EXPERIMENTAL.

Female pigeons, 90 days old, were involved in this study. A total of 8 birds were used of which 4 were injected intramuscularly with testosterone propionate (2.5 mgm. daily for 10 days) and the remaining 4 were left uninjected as controls. All the birds were kept in cages under uniform husbandry conditions throughout the duration of the experimental period.

The birds were autopsied on the day following the last injections. The uropygial glands were carefully dissected out, weighed to the nearest mgm. and fixed in cold 80% (5° to 10° C.) alcohol and in 10% formalin. After dehydration and imbedding in paraffin, serial sections were cut 6 microns in thickness. The

Senior Research Fellow, National Institute of Sciences of India.

tissue fixed in formalin was stained in Mallory's. The sections of the gland fixed in alcohol were incubated in sodium glycerophosphate substrate (pH 9.5) according to the technique of Gomori (1941) for the demonstration of alkaline phosphatase. In order to increase the enzyme activity 0.01M. magnesium sulfate was added to the substrate (Atkinson and Engle, 1947). The site of phosphatase activity in the tissue sections is marked by the deposition of cobalt sulfide in fine black or brown granules. No counterstains were used in order to avoid obscuring these deposits. The sections were dehydrated and mounted in the usual manner.

RESULTS.

Controls.—The microscopical structure of the uropygial gland in the fowl has been described by Kar (1947). In general, the histological features of this gland in the pigeon agreed with those of the fowl. The phosphatase was present in diffuse quantities in the gland. The connective tissue forming the basement membrane of the alveoli showed negative reactions for the enzyme. In the blood vessels of the basement membrane the phosphatase was present only in the endothelium. The cuboidal cells underlying the alveolar wall showed maximal reactions for phosphatase activity (Pl. II, Fig. 1). In the rest of the alveolar epithelium the enzyme activity was variable. In one or two layers of cells next to the cuboidal epithelium the enzyme reactions were stronger in the nucleus while the cytoplasmic phosphatase activity was very low (Pl. II, Fig. 1). Beyond these layers, the progressively degenerating cells showed very weak enzymatic reactions in the cytoplasm. The phosphatase activity in the nucleus of these cells was practically absent.

Androgen treatment.—Atrophic changes similar to those reported in the uropygial gland of the fowl after androgen treatment (Kar, 1947), were noted in the gland of the pigeons treated with testosterone propionate. The disintegrated cellular mass, characteristic of the alveoli of the atrophic glands was present in the central region of the alveoli (Pl. II, Fig. 2). The basement membrane showed negative reactions for phosphatase activity. In the blood vessels the enzyme was restricted to the endothelium as in the control pigeons. In the cuboidal cells beneath the basement membrane there was slight loss of phosphatase activity in the cytoplasm, while the nuclear enzyme activity was unaffected. In the rest of the alveolar epithelium the enzyme was practically absent from the cytoplasm of the component cells (Pl. II, Fig. 2). The nuclear phosphatase, however, was present in the cells. It is interesting to note that the disintegrated cellular mass in the central region of the alveoli showed slight reactions for the enzyme.

DISCUSSION.

The present studies have clearly demonstrated the presence of alkaline phosphatase in the uropygial gland of the pigeon. The enzyme is present in diffuse quantities in the gland of the normal birds. Androgenic treatments, however, depress the activity of the phosphatases, but do not abolish it, since appreciable amounts of the enzyme are present in the component tissues of the gland. The phosphatase concentration in the uropygial gland of untreated pigeons appears to be in level with that of the sebaceous glands in the golden hamster. In this mammalian species the enzyme is present in diffuse quantities in the sebaceous cells and the sebum (Montagna and Hamilton, 1947). The phosphatase disappears from the glands of castrated female hamsters, but is restored on replacement therapy with testosterone propionate.

A question may now be raised concerning the possible physiological rôle of alkaline phosphatase in the uropygial gland. It is well known today that diverse type of endocrine factors exist and that they selectively regulate the normal

functioning of various specific organs. A typical example of this diversity of endocrine function is provided by the hormonal control of the normal holocrine cycle in the uropygial gland (Kar, 1947, 1949). Unfortunately we have next to no knowledge about the mechanisms by which the hormones exert their effects.

Following the recent recognition that biochemical conversions are controlled by enzymes, the attention has been focussed upon the relationship of the hormones to these regulatory mechanisms. A number of recent studies, for instance, have revealed a relationship between the endocrine status and the activity of the phosphatases. Atkinson and Elftman (1947) studied the mobilization by estrogen of alkaline phosphatase in the uterus of mouse; Talmage (1949) demonstrated the great increase in phosphatase activity in the entire genital tract of the rat after estrogen treatment; the enzyme disappears rapidly from the uterus of rat after hypophysectomy and is restored on replacement therapy with estrogen or pituitary powder (Dempsey *et al.*, 1949); the immature oviduct of juvenile pigeons show practically negative reactions for the phosphatase, but in birds of the same age treated with sex hormones the phosphatase activity is markedly increased in the hypertrophied oviduct (Kar, unpublished data); and many other examples in the same line may be cited. In the light of these findings, therefore, it now seems probable that the relationship between the phosphatases and the hormones has a causal significance.

The present study adds a new instance in which the alkaline phosphatase activity is shown to be hormonally controlled. Since the phosphatases play a vital rôle in the intermediate metabolism of lipids (Dempsey and Wislocki, 1946), it is not unlikely that the holocrine lipoidal metabolism in this typical avian gland is mediated by the enzyme through the influence of the gonadal hormone. The evidence in support of this concept is provided by the loss of phosphatase activity in the uropygial gland of androgen treated pigeons. This decreased enzyme activity due to testosterone propionate treatment is undoubtedly associated with the disturbance of the normal holocrine order and the consequent atrophy of the gland.

PART II. THE DISTRIBUTION AND CONCENTRATION OF ALKALINE PHOSPHATASE IN THE OVARY OF NORMAL AND OF ANDROGEN TREATED PIGEONS.

INTRODUCTION.

The presence of alkaline phosphatase has been demonstrated cytochemically in the ovary of several species of mammals. In the pig, the dog, and in the human the thecal cells contain abundant phosphatase and those of the granulosa contain none (Corner, 1948). The condition is reversed in the rabbit, while in the rhesus monkey the enzyme is present in both the layers (Corner, 1944 and 1948). Alkaline phosphatase occurs ubiquitously in the ovary of the rat. It is demonstrable in the graffian follicles, corpora lutea, interstitial tissue and the blood vessels (Dempsey *et al.*, 1949). The enzyme disappears from the ovary of hypophysectomized rats but is restored on replacement therapy with pituitary powder.

Since the presence of alkaline phosphatase has not hitherto been reported in the avian ovary, it seemed desirable first to study the distribution and concentration of the enzyme in the ovary of normal pigeons, and secondly to note the effects of androgenic treatments on phosphatase activity in the gland.

EXPERIMENTAL.

The ovaries of the same normal and androgen treated pigeons which were involved in the experiment reported in the Part I of this series, were carefully dissected out and fixed immediately in chilled 80% alcohol. Paraffin sections, 6 microns in the thickness, were prepared and processed according to the technique

of Gomori (1941) for the demonstration of alkaline phosphatase. Sodium glycerophosphate was used as the substrate which was buffered to pH 9.5. The preparations were incubated in the substrate for 3 hours at 37°C. No counterstains were used in order to allow critical observation of the granular deposits of cobalt sulfide. The sections were dehydrated and mounted in the usual manner.

RESULTS.

Controls.—There was very little alkaline phosphatase in the granulosa cells of the ovary. The endothelium of the vascular wreath situated in the theca showed strong reactions for the enzyme. Moderate phosphatase activity was evident in the nucleus of the thecal cells, while the enzymatic activity in the cytoplasm of these cells was negligible (Pl. II, Fig. 3). In the stroma, the endothelium of the blood vessels and the connective tissue cells showed phosphatase reactions, but the amount of enzyme in the interstitial cells was very slight.

Androgen treatment.—The ovary was greatly hypertrophied after androgen treatment. The induced maturation of the oocytes and the marked stromal growth were evident upon microscopical examination. The phosphatase activity in the granulosa cells of the ovary was practically absent. There was, however, a spectacular mobilization of the enzyme in the theca (Pl. II, Fig. 4). The nucleus and the cytoplasm of the thecal cells as well as the endothelium of the blood vessels showed strong positive reactions for the phosphatase. The nucleus of the interstitial cells in the stroma showed slight phosphatase activity, but the enzyme was totally absent from the cytoplasm of these cells. Moderate reactions for the phosphatase were given by the stromal connective tissue cells.

DISCUSSION.

It is becoming increasingly evident that the hormones exert their regulatory effects on tissues and organs by influencing the rate of enzymatic processes. A number of recent studies have revealed a relationship between the endocrine functioning and the activity of the phosphatases (*vide* Dempsey *et al.*, 1949). These studies have clearly indicated the possibility that the relationship between the hormones and the phosphatases has a causal significance. Moreover, a series of investigations have proved beyond doubt that the phosphatases vary under different physiological conditions.

In view of the above, it is not surprising that the distribution and concentration of alkaline phosphatase in the ovary of the pigeon should change after androgenic treatments. It is well known that the injection of androgen at a suitable level causes stimulation of the avian ovary (for references see Kar, 1948). The histological consequences of this induced ovarian stimulation are the accelerated development of the follicular system and the marked stromal growth. To these, we add here an important cytochemical data, that is, the spectacular mobilization of alkaline phosphatase in the ovarian theca.

The story of the attempts to locate the possible sites for the production of the estrogenic hormones is now one of the classics of endocrinology. Efforts to collect and assay the various follicular components for estrogens showed that high concentrations occurred in the theca interna rather than in the granulosa (*vide* Dempsey, 1948). Moreover, it has been shown that lipid is a constant component of the theca interna (Dempsey, 1948). In view of these facts, it is not unlikely that the phosphatase plays some unknown rôle in the synthesis of estrogenic hormones in the ovary. The marked increase in the enzymatic activity in the ovarian theca of the testoid recipients provides an evidence in support of this concept. However, pending further studies little is to be gained by speculation concerning the possible rôle of the phosphatases in the production of estrogenic hormones in the ovary.

SUMMARY.

Part I.—Alkaline phosphatase is present in diffuse quantities in the uropygial gland of the pigeon. Androgenic treatments depress the activity of the enzyme but do not abolish it. It is suggested that the holocrine lipidal cycle in this gland is mediated by the phosphatase through the influence of sex hormone.

Part II.—In the ovary of the normal pigeons alkaline phosphatase is demonstrable in the theca, blood vessels, and the stromal tissue. Androgenic treatments cause a heavy mobilization of the enzyme in the theca. The possible rôle of alkaline phosphatase in the ovary is discussed.

ACKNOWLEDGMENTS.

The author wishes to express his indebtedness to Dr. B. Mukerji, Director, Central Drugs and Pharmacognosy Laboratories, for providing facilities for research and for constant encouragement. Grateful acknowledgment is made to Dr. K. H. Gruschwitz of Ciba Pharma, Ltd., Calcutta, for the generous contribution of testosterone propionate (Perandren) used in this study. Thanks are due to Sri P. C. Pathak for the photomicrographs which illustrate this paper.

REFERENCES.

- Atkinson, W. B., and E. T. Engle (1947). Studies in endometrial alkaline phosphatase during the human menstrual cycle and in hormone treated monkey. *Endocrinol.*, **40**, 327-333.
- Atkinson, W. B., and H. Elftman (1947). Mobilization of alkaline phosphatase in the uterus of mouse by estrogen. *Endocrinol.*, **40**, 30-38.
- Corner, G. W. (1944). Alkaline phosphatase in the ovarian follicles and corpora lutea. *Science*, **100**, 270-271.
- (1948). Alkaline phosphatase in the ovarian follicle and in corpus luteum. *Contrib. Embryol. Carnegie Inst. Washington*, **32**, 1-8.
- Dempsey, E. W., and G. B. Wislocki (1946). Histochemical contributions to physiology. *Physiol. Rev.*, **26**, 1-8.
- Dempsey, E. W. (1948). The chemical cytology of the endocrine glands. *Recent progress in hormone research*, **3**, 127-157. Academic Press Inc., New York.
- Dempsey, E. W., R. O. Greep, and H. W. Deane (1949). Changes in the distribution and concentration of alkaline phosphatase in tissues of the rat after hypophysectomy, and after replacement therapy. *Endocrinol.*, **44**, 88-103.
- Gomori, G. (1941). The distribution of alkaline phosphatase in normal organs and tissues. *J. Cell. Comp. Physiol.*, **17**, 71-83.
- Kar, A. B. (1947). The hormonal influence in the normal functioning of the uropygial gland of the fowl. *Anat. Rec.*, **99**, 75-90.
- (1948). Androgen induced changes in the sexual organs of a common Indian bird, the spotted munia, *Uroloncha punctulata* (Linn.). *Proc. Zool. Soc. Bengal*, **1**, 81-89.
- (1949). The stimulation of the uropygial gland in the female Indian spotted munia, *Uroloncha punctulata* (L.) due to oestrogen treatment. *Nature, London*, **164**, 495.
- Montagna, W., and J. B. Hamilton (1947). Histochemical analysis of the sebaceous glands of the golden hamster. *Anat. Rec.*, **99**, 560 (Abs.).
- Selye, H. (1943). Morphological changes in the fowl following chronic overdosage with various steroids. *J. Morph.*, **73**, 401-421.
- Talmage, R. V. (1949). Influence of estradiol on alkaline phosphatase activity in the genital tract of the rat. *Proc. Soc. Exp. Biol. and Med.*, **70**, 719-721.

EXPLANATION OF PLATE II

- Fig. 1. Photomicrograph of the section through the uropygial gland of a control pigeon (X 420). Note the presence of alkaline phosphatase in the alveoli.
- „ 2. Photomicrograph of the section through the uropygial gland of a pigeon treated with androgen (X 420). The enzyme has practically disappeared from the stratified epithelium of the alveoli. Note presence of disintegrated cellular mass in the central region of the alveoli.
- „ 3. Photomicrograph of the section through the ovary of a control pigeon showing the presence of alkaline phosphatase (X 140).
- „ 4. Photomicrograph of the section through the ovary of an androgen treated pigeon (X 140). Note the heavy mobilization of alkaline phosphatase in the theca of the hypertrophied ovary.



LUMINESCENCE SPECTRA OF ALKALI HALIDES.

By H. N. BOSE and J. SHARMA.

(Communicated by Prof. S. N. Bose, F.N.I.)

(Received November 14, 1949; read January 2, 1950.)

ABSTRACT.

The luminescence spectra of some of the alkali halides, pure and impurity activated, under cathode ray excitation, have been investigated at ordinary and low temperatures. It has been found that pure specimens, which are non-luminescent under ultraviolet excitation, emit a spectra composed of a number of diffuse bands. The effect of different impurities, when added to the melts or as mechanical mixtures, has been investigated in some of the cases; the effect of concentration on the luminescence spectra has been studied for the system KI+Tl. Comparing the measurements with the ultraviolet luminescence spectra of impurity activated alkali halides, it is observed that part of the emission by ultraviolet excitation can be explained as that of pure matrix emission which is obtained under X-rays or cathode rays. The existence of an emission, similar to that of TlCl, in the luminescence spectra of alkali halides with high thallium content, indicates an identical environment for Thallium ions in these phosphors and in thallos chloride. Easy transfer of excitation energy between the centres, induced by X-rays or cathode rays, and those due to activators, occurs very frequently and it is suspected that activation of alkali halides by Thallium is a case of indirect activation, for that part of the spectrum, which is common in the activated and pure alkali halides, under u.v. and X-ray or cathode ray excitation respectively.

Pure alkali halides absorb in the far ultraviolet; but several other absorption bands can be created by incorporating foreign ions or by producing stoichiometric excess in the crystal. Irradiation with X-rays is reported to produce new absorption centres known as F , F' , R_1 , R_2 , M -bands, etc. The origin and mechanism of these centres have been discussed by several authors, viz. Mott and Littleton (1938), Mott and Gurney (1940), Tibbs (1939), Seitz (1946). The existence of these centres in emission has not been proved as yet. In the case of impurity activated alkali halides, ultraviolet excitation yields complicated emission spectra. [Hilsch (1937), Von Meyeren (1930), Pringsheim (1942, 1948).]

Both X-rays and cathode rays excite the phosphors through the intermediary of photo-electrons, primarily released by the radiation. The luminescence spectra in either case are expected to be identical. Because of the high and white nature of the energies of the excited electrons, higher energy levels of the pure or disturbed lattice, if there be any, are expected to take part in the emission process, which may not be indicated by ultraviolet excitation. Besides, there is the possibility of obtaining spectrum of recombination type.

Pure alkali halides, which are generally non-luminescent under ultraviolet radiation, can be made to fluoresce by X-ray excitation, the spectra consisting of several bands (P.R.S. dissertation, H. N. Bose, 1947). Because of the poor yield of luminescence under X-rays, it seemed possible that the full features of the spectra were not obtained there and the present investigation, on the luminescence spectra by cathode ray excitation, was undertaken in order to supplement the X-ray luminescence data, in spite of the fact that the samples are less stable under such excitation. In most cases, though not always, intensity of luminescence under cathode rays is many times greater than that under X-rays; at low temperature, the intensity is greatly enhanced. The discolouration of the sample also takes place much more quickly resulting ultimately in great reduction in intensity; the

spectra could, however, be photographed, in general, before any visible spoiling of the samples takes place.

EXPERIMENTAL TECHNIQUE.

The construction of the demountable discharge tubes used in this investigation will be clear from Figure 1. The sample holder (1A) could be rotated to bring in different surfaces of the sample holder under cathode rays, so that fresh surfaces could be used when necessary. The phosphors were rubbed directly on the flattened surface of the sample holder without any adhesive. For low temperatures, liquid oxygen could be poured into the sample holder through the opening at the top which projects outside the discharge tube. A quartz window is provided for in the wall of the discharge tube facing the sample. The voltage of the tube could be varied between 5 k v to 10 k v.

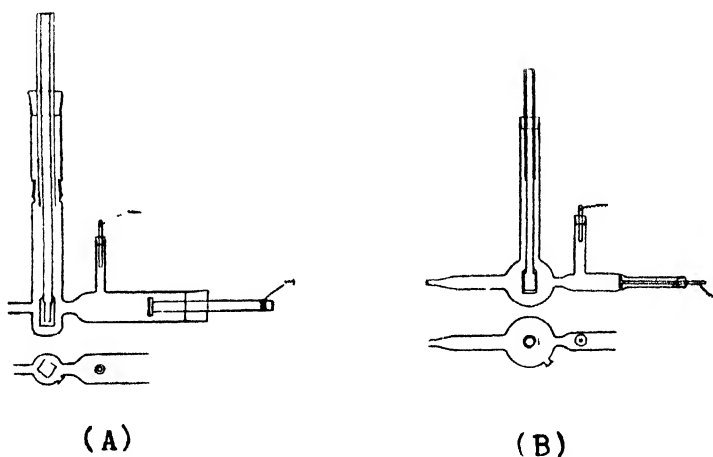


FIG. 1
Cathode ray tube with sample holder.

Impurity activated samples were prepared by mixing a measured quantity of the impurity with the pure substance and melting the mixture in furnace at about 900°C for 15 minutes when the substance melts into a clear transparent homogeneous liquid. Same conditions as regards annealing, etc. were maintained as far as possible. Three different types of plates, viz. Ilford H.P. 3, Gevaert Pan and sensitized superchrome, were used in many cases; this is sometimes essential as characteristic spectral sensitivity of the particular plate may distort the spectrum in particular region as regards its intensity as well as its structure. Obviously the substances have been studied in high vacuum so that spurious effects, if there be any, due to the water content of the hygroscopic samples or causes of similar nature were automatically eliminated. Dark discharge must be maintained during the experiment, by proper manipulation of the pressure, otherwise the appearance of molecular bands of the residual gas, specially that of nitrogen which are obtained with great ease at low temperature, may create confusion; despite all precautions, atomic lines could not be avoided in some cases. These, however, could be used as reference lines in addition to the copper lines which have been used for calibration. With a view to avoid all possible sources of error and confusion, ~~various~~ experiments were, however, carried out without any phosphor on the sample ~~under~~ under different steady conditions.

The measurements have been made on the microphotometric records but even then, it has been found that the extended nature of the emission spectra, producing a flat type of microphotometric curve limits the accuracy of measurements to about ± 20 A.U. The temperature of the bombarded sample is rather uncertain; this uncertainty of the temperature of the phosphors produces a change in some of the band positions, which further limits the accuracy of the measurements on the band maxima.

Results and discussions.

As in the case of X-ray excitation, alkali halides in the pure state, which are non-luminescent under ultraviolet irradiation, show fluorescence as well as phosphorescence under cathode rays. The luminescence spectra extend from extreme long wave-length of visible spectrum to ultraviolet region. The spectra consist of broad bands and are, in general, identical with those obtained by X-ray excitation; in some cases intensity distribution is different. On lowering the temperature of the phosphor, the intensity of luminescence is greatly increased; but no decisive change in the positions and widths of the bands could be observed even when the temperature is changed from 30° C. to -184° C.; of course, it must be remembered that temperature of the sample under cathode rays must be somewhat uncertain. Changes in the relative intensity of the different bands are, however, observed. In the following discussion the spectra at low temperature (-184° C.) have been presented.

Pure alkali halide phosphors.

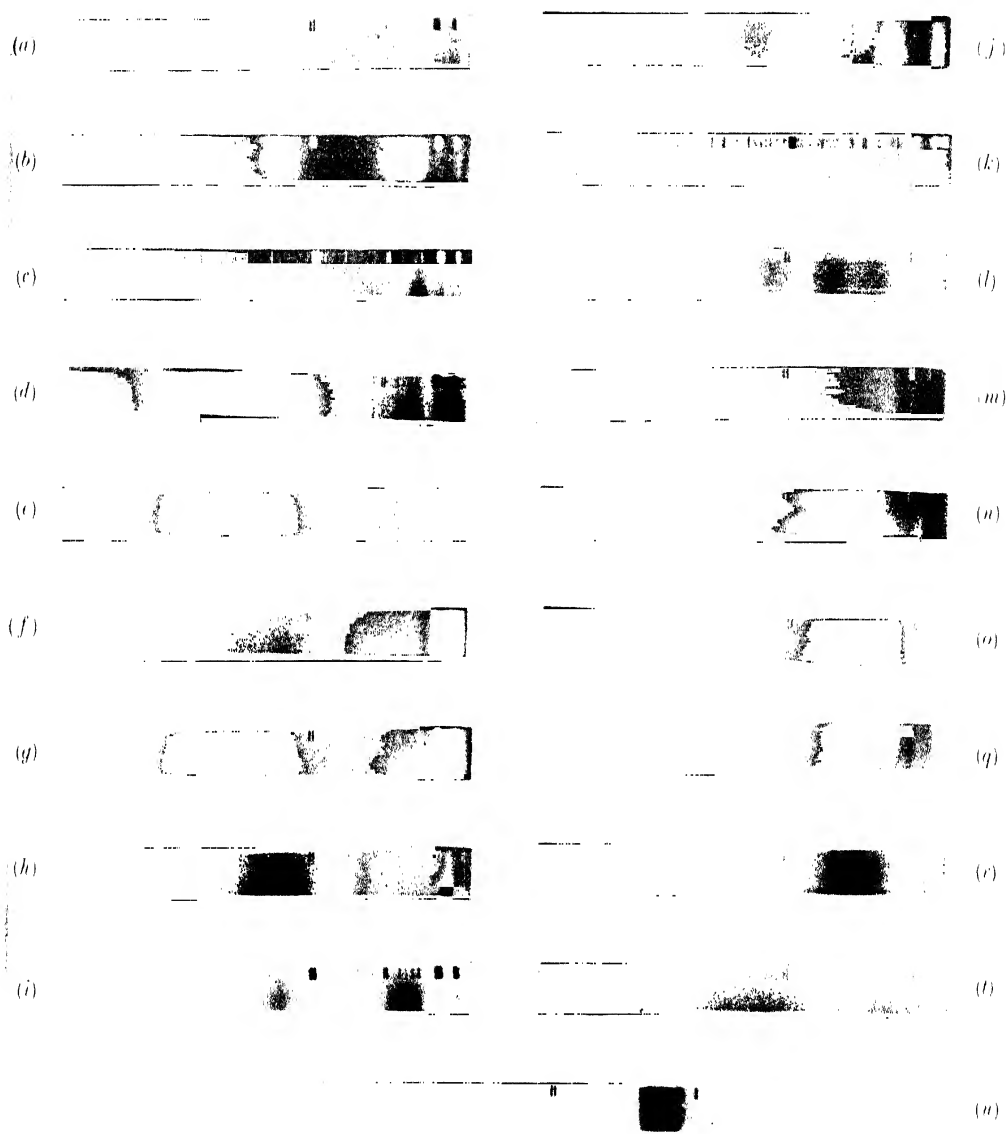
The diffuse bands, in general, superpose on each other to a great extent resulting in an extended spectrum with certain maxima; the measurements are shown in Table I. The extreme long wave-length band at λ 6500 (approx.), which is obtained in all cases, is rather sharp compared to other bands; it seems possible that the band actually extends into the infra-red region, and only a part of the band limited by the sensitiveness of the plate appears in the spectrum. The absence of the band in some cases, as shown in Table I, is due to the use of non-panchromatic plates; but visual examination always reveals its existence in the spectrum. Some of the structures in the long wave-length part are not obtained with quartz spectrograph because of less dispersion and low transmission in this region.

At low temperature colouration of the samples takes place very quickly and more intensely, release of electrons from the traps taking place less easily at low temperature. It is known that on intense exposure, deposit of alkali metal atoms takes place on the surface of the alkali halide crystals; luminescence by cathode ray being rather a surface phenomenon, the penetration of excitation energy inside the coloured crystal does not take place to the same extent as in the case of unexposed ones. Besides, the different parts of the spectrum are absorbed to a different extent so that the spectrum presents an altered appearance, so far as the relative intensities of the different bands, are concerned. In case of X-rays, excitation takes place throughout the entire volume of the crystals; this will probably explain the difference in behaviour in the two cases. The temperature effect on the luminescence spectra can also be partly explained in this way; of course, the radiative mechanism at the individual emitting centres may be responsible too. In potassium bromide and potassium chloride the samples are coloured much more quickly and intensely, than in the case of others; consequently in this case shorter wave-length parts of the spectra are very weak at room temperature and could not be obtained even at low temperature.

In the case of sodium bromide several sharp bands λ 4130, 3940, 3740, 3570 Å.U. are obtained only in the case of fresh samples while after exposure for some time

TABLE I.
Extensions and prominent peaks of the luminescence spectra.

	NaCl.		NaBr.		NaI.		KCl.		KBr.		KI.		LiCl.		TlCl.	
	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.
Extensions ..	6600-4900	1.87-2.52	6600-5100	1.87-2.42	6600-5100	1.87-2.42	6600-5100	1.87-2.42	6600-6250	1.87-1.97	6600-4600	1.87-2.68	6600-6100	1.87-2.02	6230-4280	1.98-2.89
Peaks ..	6530-5810-5520	1.89-2.12-2.24	6510	1.90	6540-5890-5430-5160	1.88-2.10-2.27-2.39	6520	1.89	6520	1.89	6520-5920-5380-5240-4730	1.89-2.08-2.29-2.36-2.61	6460	1.91	6200-5850-5085-4580	1.99-2.11-2.43-2.69
Extensions ..	4900-3250	2.52-3.80	4600-3500	2.68-3.53	4000-3500	3.09-3.53	5100-?	2.42-?	6200-3360	1.99-3.67	4700-3300	2.63-3.74	6100-5100	2.02-2.42		
Peaks ..	3980-3550	3.10-3.48	4130-3940-3740-3570	2.99-3.13-3.30-3.46	3745	3.30			5740-5400-5140-4480-4280-3660	2.15-2.29-2.40-2.75-2.91-3.37	4130-3870	2.99-3.19	5860-5400-5170	2.11-2.29-2.39		
Extensions ..			3350-2500	3.68-4.94	3350-2600	3.68-4.75							5100-4060	2.42-3.09		
Peaks ..			Continuous		3000	4.11							4570	2.70		
Extensions ..													3680-2650	3.35-4.66		
Peaks ..													3000	4.11		



Luminescence spectra of some of the alkali halides at liquid oxygen temperature under cathode rays with quartz spectrograph. 'p' and 's' refer to panchromatic and super-chrome plates respectively.

(a) NaCl (p); (b) NaCl : Tl 2.5% (p); (c) NaCl : Tl, mixture (p); (d) NaBr (p); (e) NaBr (p), showing line structure peaks; (f) NaBr : Tl 2.5% (p); (g) NaBr : Tl, mixture (p); (h) NaI (s); (i) KCl : Tl 2.5% (p); (j) KCl : Tl, mixture (p); (k) KBr (p); (l) KBr : Tl 2.5% (s); (m) KBr : Tl, mixture (p); (n) KI (s); (o) KI : Tl 5% (s); (p) KI : Tl, mixture (p); (q) KI : Mn 5% (s); (r) LiCl (s); (s) TlCl (s).

these separate band maxima disappear, yielding place to a continuous extension. It is not possible to explain this behaviour without more accurate knowledge about the nature of the emitting centres; but it seems that continuous irradiation causing greater concentration of the emitting centres somehow modifies the nature of the particular centre; the effect may also be due to an uncertain rise of temperature in the immediate vicinity of the bombarded ions.

The mechanism of luminescence of pure alkali halides under X-rays or cathode rays is an involved process and the nature of the emitting centres obscure. It must be admitted that, in spite of great precaution, the samples may still contain minute traces of impurities. But samples used have been found to show no luminescence under ultraviolet irradiation in the solid state or in solution. So the method of excitation appears to be responsible for the behaviour. Most of the work of previous workers on the luminescence spectra of alkali halides, activated by impurities, deals with excitation by the wave-lengths of the new absorption region; on comparison it is found that the emission spectrum is, partly at least, composed of that due to the parent lattice, as obtained in the present investigation. Under X-rays or cathode ray excitation, energy is absorbed by the whole lattice so that emission is mostly due to the transfer of excitation energy from the parent lattice to emitting centres through the intermediary of internal photo-electrons moving through the conduction band; emission due to the direct excitation of centres, as takes place in the case of ultraviolet excitation, is rather small in this case. The electrons from the conduction band are profusely trapped inside the crystal and phosphorescence is obviously due to the electrons leaking thermally into the excited states of the emitting centres. It thus seems natural to assume that emission is due to electrons falling into the excited states of the emitting centres from the conduction band.

The exposure of alkali halide crystals to X-rays or cathode rays is known to create several absorption centres (F , F' , R_1 , R_2 , etc.) which have been discussed and elucidated by Seitz (1946); occurrence of these centres in emission has not been established; besides, no systematic agreement of the present measurements with the absorption data is obtained, and the temperature dependence of the emission spectrum is not so well marked as in the case of absorption bands. We are thus led to believe that the emission is due to centres possibly created by internal ionisation due to X-rays or cathode ray irradiation such that the excited states of the centres lie very close to the conduction band. It is interesting to note in this connection that in the valence band spectra of these compounds (Das Gupta, 1947) in the soft X-ray region, several peaks are obtained; if internal transition is assumed, some of the bands in the luminescence spectra may be explained. This mechanism is specially favourable for the emission of the long wave-length band at λ 6500 (approx.), for, the separation between the prominent peaks of the valence band is approximately 2 volts; further, this band decays so quickly that it could not be detected in the afterglow emission. The afterglow is too weak for its spectrum to be recorded, but was examined visually only.

Impurity activated alkali halide phosphors.

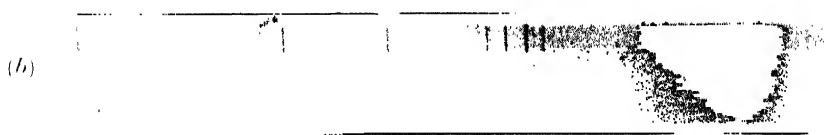
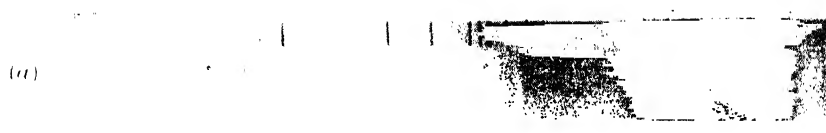
Luminescence spectra of some of the alkali halides activated by thallium and other impurities have been measured and the measurements are given in Tables II and III. The spectrum is different from that obtained by excitation with new absorption bands created by activation (Von Meyer, 1930). It has been found that in many cases alkali halides under X-ray or cathode ray excitation, do not show the characteristic impurity band in emission which is known to be emitted when excited by the absorption band due to the activator.

Thus impurities like Mn, Cu, U, Pb, Ag, etc. are well-known activators for alkali halides under ultraviolet excitation, the corresponding emission which may be

TABLE II.

Extensions and peaks of the luminescence spectra of impurity activated alkali halides.

	NaCl+Ti 2.5%		NaBr+Ti 2.5%		KCl+Ti 2.5%		KBr+Ti 2.5%		KI+Ti 0.1% 0.5%		KI+Ti 5%		KI+Mn 2.5%	
	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.	A.U.	e.v.
Extensions	6600- 4900	1.87- 2.52	6600- 5100	1.87- 2.42	6600- 5100	1.87- 2.42	6600- 6250	1.87- 1.97	4700- 3300	2.63- 3.74	6600- 5200	1.87- 2.37	6600- 5200	1.87- 2.37
Peaks	6530 5810 5520	1.89 2.12 2.24	6510	1.90	6540 5890 5430 5160	1.88 2.10 2.27 2.39	6520	1.89	3420	3.61				
Extensions	4900- 3250	2.52- 3.80	4600- 3500	2.68- 3.53	5100- 3500	2.42- 3.53	6200- 3300	1.99- 3.67			5200- 3200	2.37- 3.86	5100- 3250	2.42- 3.80
Peaks	3980 3550	3.10 3.48	4130 3940 3740 3570	2.99 3.13 3.30 3.46	4390 3910	2.81 3.16	5740 5400 5140 4480 4280 3660	2.15 2.29 2.40 2.75 2.91 3.37					3420	3.61
Extensions	3250- 2650	3.80- 4.66	3350- 2500	3.68- 4.94	3200- 2800	3.86- 4.41	3350- 3000	3.69- 4.12						
Peaks	3000	4.11	3100 2780 2600	3.98 4.44 4.75	3020	4.09	3160	3.90						



Luminescence spectra of KI phosphors with glass spectrograph at room temperature.
 (a) KI pure; (b) KI + U (low conc.); (c) KI + U (high conc.); (d) KI + Pb.

of the characteristic or transfer type, occurring in each case. In the case of many of these phosphors, under cathode rays or X-rays excitation the characteristic impurity emission is absent in the luminescence spectra; the luminescence spectrum of the parent lattice is obtained, altered in intensity and sometimes partly quenched by the impurities. In some cases, of course, additional emission bands appear but emission due to the unactivated sample is always present, though the intensity distribution of the spectrum is modified. Thus the luminescence spectrum of $\text{NaCl}+0.01\%$ of Cu is practically the same as that of pure sodium chloride. With

TABLE III.

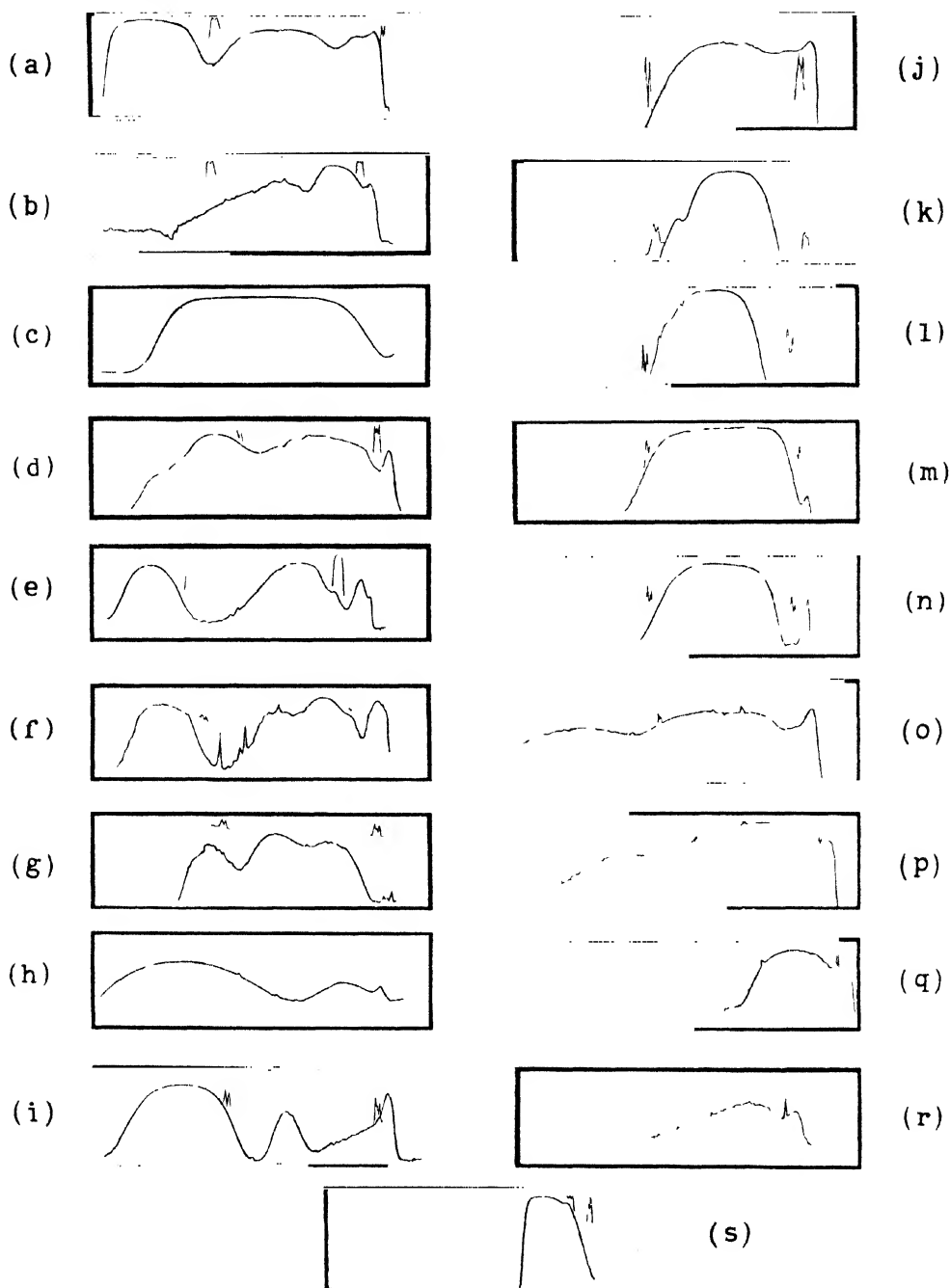
Luminescence spectra of KI with impurities at room temperature with glass spectrograph.

		KI+U low %		KI+U high %		KI+Pb	
		A.U.	e.v.	A.U.	e.v.	A.U.	e.v.
Extensions	..	6600-4700	1.87-2.63	6600-4700	1.87-2.63	6600-5200	1.87-2.37
Peaks	..	6520	1.89	6520	1.89	6520	1.89
		5920	2.09	5920	2.09	5920	2.09
		5380	2.30	5380	2.30	5380	2.30
		5240	2.36	5240	2.36		
		4730	2.61	This peak is suppressed almost completely.			

a view to study the effect of impurities on the luminescence spectrum, samples of potassium iodide activated by Pb, U, Ag, Be and Mn were prepared and its luminescence spectra under cathode rays investigated. Although the effect of concentration has not been studied in all cases, it has been found, in general, that, unlike the case of ultraviolet excitation, the effect of impurity is not very pronounced at very low concentration of the impurity; so moderately high concentration of the activators has been used throughout.

The presence of Pb or U, results in a quenching of the emission spectrum on the short wave-length side; if the activator concentration is increased quenched region extends further on the longer wave-length side. The total intensity of luminescence is not increased perceptibly. In the case of KI+Be, the band with a peak at λ 3420 A.U. becomes rather prominent without affecting the spectrum in any other way; this band, though suspected in the emission of KI alone, is very weak so that it appears there only as an extension continuous with the preceding ones. Similar effect is obtained also in the case of KI+Mn and KI+Ag, in which, further, additional emission bands in the visible region are superposed on the emission due to KI alone, thereby obliterating the peaks in this region. The longest wave-length part of the emission spectrum, however, remains unaffected in all these cases.

A large amount of work has been done by previous workers (Von Meyer, 1930, Pringsheim, 1942, Hutton and Pringsheim, 1948, etc.) on the emission and absorption spectra of Thallium activated alkali halides under ultraviolet irradiation. Some of these measurements are given in Table IV for comparison. The behaviour of single crystals containing small percentage of thallium concentration is not identical with that of powders containing higher concentration (Pringsheim, 1942). It is found that the luminescence spectra of alkali halides activated by thallium consist of a band obviously due to the activator in addition to the parent lattice emission and the relative intensities of the different bands in the spectra are modified by its inclusion. It also seems obvious that part of the emission spectra generally assigned to thallium, is obtained even for the pure alkali halides without any thallium.



Microphotometric records of the luminescence spectra of some of the alkali halides under cathode rays.

(a) NaCl+Tl 2.5%; (b) NaCl+Tl mixture; (c) NaBr, last band only is shown; (d) NaBr+Tl 2.5%; entire spectrum is given, the last band beginning from the reference lines on the left; (e) KCl+Tl 2.5%; (f) KCl+Tl mixture; (g) KBr+Tl 2.5%; (h) LiCl; (i) NaI; (j) KI; (k) KI+Tl 1%; (l) KI+Tl 5%; (m) KI+Tl 5%; (n) KI+Mn 5%; (o) KI; (p) KI+U, low conc.; (q) KI+U, high conc.; (r) KI+Pb; (s) TlCl; figures (o) to (r) refer to room temperature with glass spectrograph.

Thallium bands are known to be highly sensitive to temperature (Von Meyer, 1930); so accurate agreement is not expected.

The band due to thallium is obtained in $\text{NaCl}+\text{Tl}$ and $\text{NaBr}+\text{Tl}$ in the extreme short wave-length part of the spectrum. The same band is absent in the case of mechanical mixtures which yield spectra composed of independent mixture of thalious chloride and the halide. The luminescence spectrum of pure sodium bromide is characterized by a very strong band in the ultraviolet, extending continuously from λ 3350 to 2500 Å.U. (perhaps even beyond); with thallium, the short wave-length part of the band is quenched up to λ 3000 and other bands with peaks at λ 2780 and 2600 Å.U. are obtained; the spectrum in this region thus shows two distinct maxima with probable weak components. These are obviously the two peaks obtained in the luminescence spectrum of $\text{NaBr}+\text{Tl}$ under ultraviolet excitation. At room temperature, i.e. 30°C ., the shorter wave-length peak is the stronger of the two, while at -184°C ., the longer wave-length maxima becomes more prominent.

Seitz (1939, 1938) has described the mechanism of absorption and emission process of thallium activated alkali halides in terms of the energy levels of thallium ions modified by lattice influence; the absorption is due to the transition $^1S_0 \rightarrow ^3P_{1,2}$ and $^1S_0 \rightarrow ^1P_1$ while $^3P_{1,2} \rightarrow ^1S_0$ occurs in emission. Working with powdered crystals Pringsheim (1942) has observed that visible luminescence is also shown by those phosphors, specially with higher thallium content. Thus the mechanism suggested by Seitz cannot explain the whole of the spectrum. The present measurements indicate that for $\text{NaCl}+\text{Tl}$ and $\text{NaBr}+\text{Tl}$, only the shortest wave-length band should be taken as that due to thallium ions. Considering all these results, we are thus led to believe, for thallium activated alkali halides, that just as energy absorbed by the parent lattice is transferred to the impurity levels where recombination and emission occurs, the excitation energy from the thallium centres may also be transferred to the emitting centres of the parent lattice. It seems that in $\text{NaBr}+\text{Tl}$, energy is transferred to the thallium centres from a part of the excited states responsible for the short wave-length band of sodium bromide; and the amount of transferred energy depends on temperature. Thus this emission seems to be predominantly of the transfer type. The temperature dependence of the relative intensity will depend also on the dissipative mechanism at each centre and its dependence on temperature.

Such interdependence of the two emission bands makes us believe that the particular excited states of thallium is close to the excited states responsible for the extended band of sodium bromide and radiationless transition occurs from the upper part to the excited state of thallium. A possible energy level scheme is shown in Fig. 2.

The behaviour of thallium activated potassium compounds is somewhat different from those of sodium. In potassium chloride, bromide and iodide, identical spectra are obtained for mechanical mixtures and the phosphors prepared from melts. As has been shown by Pringsheim, in these cases complex formation takes place very easily. On activation by thallium, the visible luminescence specially on the long wave-length side is considerably diminished in intensity for potassium bromide and chloride while the short wave-length part becomes more prominent; in both cases the band of shortest wave-length seems to be due to thallium centres. In order to study the effect of thallium in detail, samples of $\text{KI}+\text{Tl}$ phosphors were prepared with different concentrations and their luminescence spectra investigated. At low concentration of thallium (up to 0.5%) the long wave-length bands λ 5920, 5380, 5240, 4730 Å.U. of the parent lattice, diminishes in intensity, while the short wave-length part of the spectrum increases in intensity, and band λ 3420 Å.U. (found also in the case of $\text{KI}+\text{Mn}$, $\text{KI}+\text{Be}$, etc.) becomes prominent. At higher concentration the short wave-length bands are gradually weakened, while the long wave-length bands are intensified. It is further found that at higher concentration the emission due to pure thalious chloride is superimposed on the main

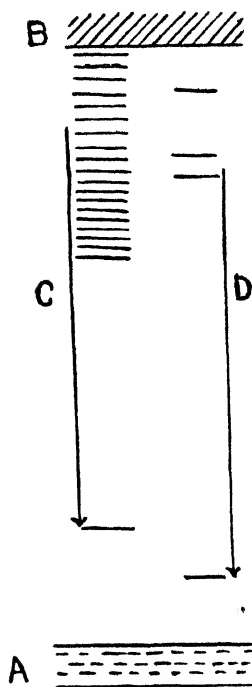


FIG. 2.

- A—Filled band.
 B—Conduction band.
 C—Levels of unactivated NaBr.
 D—Levels of Thallium ion.

pattern; thalious chloride yields, under cathode rays, intense band systems in the visible region. It has been observed by Hutten and Pringsheim (1948) that thalious chloride in the presence of traces of moisture re-acts with potassium iodide. The present phosphor, therefore, contains traces of potassium chloride (according to Hutten and Pringsheim, traces of KCl is essential for the visible luminescence of KI+Tl under ultraviolet excitation). But the additional emission that is obtained at high concentration is that of thalious chloride. This indicates that most of the added material remains as such or in a configuration similar to that of thalious chloride. Besides, in the spectrum of KI+Tl, the intensity of visible luminescence is greatly increased possibly by the emission of a strong band in the blue region (peak at λ 4200 approx.); exact measurement of this peak is not possible for, the superposition of this band on the emission spectrum of pure potassium iodide makes the band maxima indistinguishable.

Unlike other alkali halides, in KI+Tl there is no band in the ultraviolet which can be unequivocally assigned to Tl-centre; increased visible emission is possibly due to complex formation and thalious chloride as such. In the case of KCl+Tl and KBr+Tl also an emission band at about (λ 4500–4600) is suspected; it should be remembered that absorption due to F-centres in these crystals may reduce the intensity of an emission band in this region. Thus there is indication of an emission mechanism, which may be due to complex formation in the case of K-halide+Tl, besides those in the case of Na-halides+Tl. The relative intensity of the band

system in the pure and thallium activated crystals may be explained by an energy level scheme similar to that suggested in the case of NaBr+Tl.

Although the exact nature of the emission centres in alkali halides is still obscure, some general ideas can be obtained from the present investigation. Absence of luminescence by ultraviolet excitation indicates that the emitting centres are absent in pure crystals, and they are created by X-ray or cathode ray irradiation. In view of the fact that inclusion of foreign impurities results in an emission of X-ray or cathode luminescence spectrum of pure alkali halides in most cases, it is natural to suppose that the emitting centres are sometimes induced also by activation by impurities. Besides, easy transfer of energy takes place between the two types of centres in all cases; since the samples are known to be non-conducting under these conditions, transfer of energy takes place either by quantum mechanical resonance process or by self-absorption. But as the same emitting centres are created by X-rays or cathode rays and impurity inclusion, it is natural to suppose that parent matrix emission is due to the energy states of the ions perturbed by the presence of the impurity ions and it is a case of indirect activation. Further the luminescence spectrum under X-rays or cathode rays being due to the re-combination of free electrons from the conduction band with the different emission centres, only those centres which have excited states near to the conduction band, will be naturally more effective than those having excited states far below the conduction band. This may be the explanation why the impurities, which are very effective activators in ultraviolet excitation, do not play as important a rôle in the case of X-ray or cathode ray excitation.

Our thanks are due to Prof. S. N. Bose, Khaira Professor of Physics, University of Calcutta, for facilities of work and the kind interest that he has taken during the progress of the work. One of the authors (Bose) acknowledges his grateful thanks to the National Institute of Sciences of India, for providing him with the I.C.I. Fellowship and a research grant for carrying out the investigation.

REFERENCES.

- Das Gupta, K. (1947). Second order Chlorine K-valence band spectra of chlorides. *Ind. J. Phys.*, **21**, 129.
- Hilsch, R. (1937). Über die Diffusion und Reaktion von Wasserstoff in KBr-Kristallen. *Ann. d. Phys.*, **29**, 407.
- Hutton, E. H. and Pringsheim, P. (1948). A new method of preparing strongly luminescent Thallium activated alkali halides and some properties of these phosphors. *J. Chem. Phys.*, **16**, 241.
- Mott, N. F. and Gurney, R. W. (1940). *Electronic process in ionic crystals* (Oxford), 109.
- Mott, N. F. and Littleton, M. J. (1938). Conduction in polar crystals, I. Electrolytic conduction in salts. *Trans. Farad. Soc.*, **34**, 485.
- Pringsheim, P. (1942). Fluorescence and Phosphorescence of Thallium activated potassium-halide phosphors. *Rev. Mod. Phys.*, **14**, 132.
- Seitz, F. (1938). Interpretation of the properties of Alkali Halide-Thallium Phosphors. *J. Chem. Phys.*, **6**, 150.
- (1939). An interpretation of crystal luminescence. *Trans. Farad. Soc.*, **35**, 74.
- (1946). Color centers in Alkali Halide crystals. *Rev. Mod. Phys.*, **18**, 384.
- Tibbs, S. R. (1939). Electron energy levels in NaCl. *Trans. Farad. Soc.*, **35**, 1471.
- von Meyeren, W. (1930). Über die Lichtemission einiger Tl-haltiger Alkali-halogenidphosphore. *Zt. f. Phys.*, **61**, 321.

STUDIES IN HEXAMETAPHOSPHATES: PART I.

PREPARATION AND PROPERTIES OF SODIUM HEXAMETAPHOSPHATE AND A STUDY OF THE EXTENT OF COMPLEX FORMATION WITH CALCIUM IONS BY CONDUCTIVITY DATA.

By R. C. MEHROTRA and N. R. DHAR, *Chemical Laboratories, The University of Allahabad, Allahabad.*

(Received October 10; read November 25, 1949.)

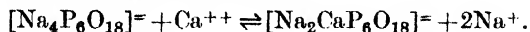
An impure form of sodium hexametaphosphate was prepared by T. Graham (1833) and some of its simple properties were studied by G. von Knorre (1892, 1900), M. Berthelot and G. Andre (1897) and Tantar (1898). G. Tammann (1890, 1892) studied the conductivities of sodium hexametaphosphate solutions in water and concluded that the hexametaphosphate showed conductivity differences characteristic of a dibasic acid.

A detailed study in the preparation and properties of pure forms of sodium metaphosphate was carried out by P. Pascal (1923, 1924, 1932). According to him, sodium hexametaphosphate is best prepared by fusing the trimetaphosphate in small portions at a time in a platinum crucible to about 700°C. and rapidly cooling the fused mass by plunging the bottom of the crucible in cold water. Pascal (1924) also investigated qualitatively the complex forming properties of sodium hexametaphosphate and found that its solutions dissolve calcium oxalate, decolorize ferric thiocyanate and prevent the coloration of uranyl salts by potassium ferrocyanide and concluded that these reactions are possibly due to the formation of the complexes, $\text{Na}_4[\text{Ca}(\text{PO}_3)_6]$, $\text{Na}_2[\text{Fe}(\text{PO}_3)_6]$, and $\text{Na}_4[\text{UO}_2(\text{PO}_3)_6]$.

A renewed and profitable interest in the hexametaphosphates was provided by the discovery of Hall (1934, 1935) that the sodium hexametaphosphate can be used as a very efficient water softener, because it has the power of sequestering calcium and magnesium ions probably due to the formation of the complexes of the type assumed by Pascal. The substance under the trade name of Calgon is now extensively used in water softening and for many other allied purposes (Rosenstein, 1936).

Thomson (1936) showed qualitatively that the complex forming power of the metaphosphate is not limited to alkaline earth ions only.

O. Stelling and G. Frang (1941) studied nephelometrically the calcium ion sequestering power of sodium hexametaphosphate and came to the conclusion that an equilibrium of the following type exists:



Campbell and Schenker (1946) carried out a polarographical study of the barium ion removal of the complex metaphosphates and arrived at similar conclusions.

As the above account shows, no systematic attempt has been made to study by quantitative and physicochemical methods the nature and composition of the complexes formed by sodium hexametaphosphate with different ions. In view of the great technical importance of the substance in recent years, it was considered of interest to study the nature of these complexes by different methods. As a result of these investigations extending over a number of years, the nature and composition of these complexes has been elucidated and moreover, many of them have been prepared in the solid state.

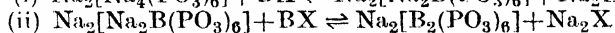
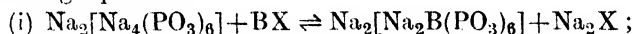
EXPERIMENTAL.

A pure sample of sodium hexametaphosphate was prepared according to the method of Pascal (1923). Microcosmic salt, $\text{NaNH}_4\text{HPO}_4 \cdot 4\text{H}_2\text{O}$ (Merck Extra Pure quality) or mono-sodium di-hydrogen phosphate (Kahlbaum Proanalysis sample) was slowly heated to red heat in a platinum crucible, till the evolution of ammonia and water vapour stopped. The temperature was now gradually raised to about 700° , when the whole mass melted to a clear transparent liquid. The transparent liquid was kept at this red heat temperature from four to six hours and then it was suddenly cooled by dipping the bottom of the crucible in ice cold water, when the liquid solidified to a transparent vitreous mass. Small amounts of the glassy substance thus obtained were again fused as in the above procedure and then suddenly cooled. The small amount of the metaphosphate ensures a rapid cooling of the inner layers of the glass also. The pure hexametaphosphate thus prepared was kept in a desiccator over concentrated sulphuric acid. It has been observed during the course of these studies that the hexametaphosphate thus produced does not show any alteration in its properties over a period as long as ten to twelve months. The substance was powdered finely and dissolved in conductivity water. The substance though quite soluble has a low velocity of solution.

Properties of the sodium hexametaphosphate.—The molecular weight of the sodium hexametaphosphate thus prepared was determined by lowering of the freezing point method and showed a value of the order of 640, after applying the correction due to ionic dissociation in aqueous solution.

A 5% solution of the substance was prepared in water and the reactions with the metallic salt solutions were observed. Solutions of soluble salts of calcium, strontium, barium, magnesium, zinc, manganese, lead, aluminium, beryllium, lanthanum, thorium, zirconium and cerium gave white gelatinous precipitates with the hexametaphosphate solution, but in all the above cases the precipitate thus formed dissolved in excess of sodium hexametaphosphate. The hexametaphosphate solution reacted with ferric and uranyl ions also in such a way as to suppress the tests of these ions altogether so that they gave no coloration with thiocyanate and ferrocyanide respectively.

As demonstrated by the above reactions, the sodium hexametaphosphate has got a sufficiently strong tendency of sequestering calcium, strontium, barium, lead, iron and other ions. This tendency is also exhibited by its property to dissolve insoluble salts—calcium oxalate, strontium carbonate, barium sulphate and lead sulphate. Similar to the reactions postulated by Pascal (1923) and other workers for the dissolution of calcium salts and sequestration of calcium ions, the reactions responsible for the dissolution of the above insoluble salts may be represented by the following equations:



(where BX stands for CaC_2O_4 , CaCO_3 , SrCO_3 , SrSO_4 , BaSO_4 , or PbSO_4).

The extent to which the various insoluble salts will go into solution will depend on the 'instability constant' of the complex ion formed and also on the solubility product of the sparingly soluble salt itself. If the above scheme represents the true state of affairs, then on the addition of an insoluble substance like calcium oxalate, the complex sodium calcium hexametaphosphate is formed and the calcium oxalate is replaced by an equivalent amount of soluble sodium oxalate. Therefore, the specific conductivity of the mixture should show an appreciable increase as the reaction proceeds forward and this increment in conductivity will give a measure of the amount of sodium oxalate that has gone into solution and consequently of the calcium oxalate dissolved.

In the following Table 1 are recorded the conductivities of sodium hexametaphosphate solutions at various dilutions at 30.0°C ., 25.0°C . and 20.0°C . and in the

Tables 2 and 3 are given the conductivities of these solutions when saturated with insoluble salts of calcium :—

TABLE 1.

Concentration of the $\text{Na}_6(\text{PO}_3)_6$ solution.	Conductivities at 30.0° C.		Conductivities at 25.0° C.		Conductivities at 20.0° C.	
	Specific.	Molar.	Specific.	Molar.	Specific.	Molar.
M/8	0.01946	156.2	.. ..	.. ..	.. ..	.. ..
M/16	0.01116	178.6	.. ..	.. ..	.. ..	.. ..
M/32	0.00598	191.3	0.004970	159.0	.. ..	.. ..
M/64	0.003230	206.7	0.002708	172.8	0.002265	145.0
M/128	0.001749	223.9	0.001451	185.6	0.001284	164.1
M/256	0.000968	247.9	0.000790	202.2	0.000708	181.2
M/512	0.000509	260.8	0.000428	219.1	0.000382	195.8
M/1024	0.0002765	283.1	0.0002375	242.7	0.0002034	208.3
M/2048	0.0001557	318.8	0.0001320	270.0	0.0001117	228.8
M/4096	0.0000890	364.4	0.0000736	301.5	0.0000606	249.0
M/8192	0.0000488	399.7	0.0000409	332.5	0.0000336	275.5

Conductivities of sodium hexametaphosphate solutions when shaken with sparingly soluble salts of calcium.—As stated earlier, the extent of dissolution of the sparingly soluble (or so-called insoluble) calcium salts for example calcium carbonate and oxalate can be found out by the increment in specific conductivity shown by hexametaphosphate solutions when shaken to saturation with these insoluble salts. For this purpose, conductivities of sodium hexametaphosphate solutions were carefully measured and then they were shaken in Jena bottles with pure calcium carbonate and calcium oxalate. The conductivities of these suspensions were measured daily and it was found that the conductivities observed after 3 days differed from those on the next (4th) day by less than 1% in general and hence, this value was taken as the saturation value. During the investigation, blanks were performed by measuring the conductivities of hexametaphosphate solutions after being allowed to stand alone under identical conditions for 4 to 5 days and it was found that these solutions generally did not show a variation in conductivity greater than 1 to 2%. This small difference was ignored and the original conductivities of hexametaphosphate solutions were taken as constant.

TABLE 2.

Specific conductivities at 25.0° C. of sodium hexametaphosphate solutions when alone and when shaken with calcium carbonate and calcium oxalate.

Concentration of $\text{Na}_6(\text{PO}_3)_6$ solution.	Sp. Cond. of the solution alone.	Sp. Cond. of the solution when saturated with calcium carbonate.	Sp. Cond. of the solution when saturated with calcium oxalate.
M/128	0.001454	0.002710	0.002645
M/256	0.000796	0.001498	0.001420
M/512	0.000430	0.000826	0.000820
M/1024	0.000237	0.000537	0.000513
M/2048	0.000132	0.000293	0.000280
Water	1.2×10^{-6}	3.21×10^{-6}	1.58×10^{-6}

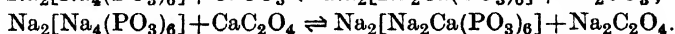
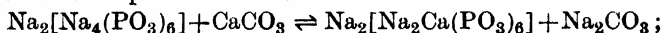
TABLE 3.

Specific conductivities at 30.0° C. of sodium hexametaphosphate solutions when alone and when shaken with calcium carbonate and calcium oxalate.

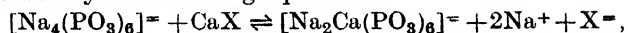
Concentration of $\text{Na}_6(\text{PO}_3)_6$ solution.	Sp. Cond. of the solution alone.	Sp. Cond. of the solution when saturated with calcium carbonate.	Sp. Cond. of the solution when saturated with calcium oxalate.
M/4 ..	0.03340	0.05130	..
M/8 ..	0.01950	0.03350	..
M/16 ..	0.01120	0.01860	..
M/32 ..	0.00592	0.00996	..
M/64 ..	0.003241	0.005563	0.004648
M/128 ..	0.001740	0.003432	0.003243
M/256 ..	0.000961	0.001931	0.001798
M/512 ..	0.000506	0.001098	0.001047
M/1024 ..	0.0002791	0.0006096	0.0006067
M/2048 ..	0.0001562	0.0003303	0.0003346
Water ..	1.4×10^{-6}	3.6×10^{-6}	1.9×10^{-5}

DISCUSSION.

As stated above, the mechanism of the dissolution of calcium carbonate and oxalate has been postulated as:



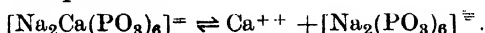
Putting the above equations in the ionic form, the mechanism may be represented by the following equation:



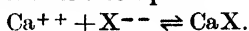
(where X^- stands for carbonate or oxalate ion).

The equilibrium of the above reaction, i.e., the extent to which the insoluble salt goes into solution would depend upon the following factors:

(1) *Instability constant or the stability of the complex ion formed.*—The factor would determine the concentration of calcium ions that arises from the secondary dissociation of the complex ions:



(2) *Solubility product of the sparingly soluble salt.*—As shown by the mechanism assumed above, each molecule of the insoluble salt dissolved is replaced by a mole of its anions. These anions will be in equilibrium with the calcium ions, arising from the secondary dissociation of the complex:



So, the dissolution of the sparingly soluble salt will stop at the stage when the ionic product of calcium ions and the anions is equal to the solubility product of the salt dissolved. Thus, in addition to the instability constant of the complex formed, the solubility product of the insoluble salt will also control the extent of its solubility. For example, calcium carbonate has got a greater solubility product than calcium oxalate. So, a greater concentration of carbonate ions will be required than that of oxalate ions, before the solubility product of the corresponding insoluble salt is exceeded. Hence, in the same concentration of sodium hexametaphosphate solution, calcium carbonate will dissolve to a greater extent than calcium oxalate (the solubility being measured in moles of the salt).

(3) *The dilution of the sodium hexametaphosphate solution.*—If the reaction represented by the above equation goes to completion, the molar concentration of the anions of the insoluble salt (appearing in the solution as a result of the dissolution with complex formation) would be equal to the initial concentration of the sodium hexametaphosphate solution. Thus, as the dilution of the hexametaphosphate solution is increased, the concentration of the anions brought into solution as a result of complex formation decreases. Hence, the reaction would have a greater tendency to go to completion in the more dilute solution, as the resulting concentration of the anions being less, there would be a lesser possibility of the solubility product of the insoluble salt being exceeded.

Assuming that the specific conductivity of the complex, $\text{Na}_2[\text{Na}_2\text{Ca}(\text{PO}_3)_6]$, is of the same order as that of the simple sodium salt, $\text{Na}_2[\text{Na}_4(\text{PO}_3)_6]$, the increase in specific conductivity that occurs when a sodium hexametaphosphate solution is shaken with calcium carbonate or oxalate may be ascribed to the sodium carbonate or sodium oxalate formed plus the specific conductivity of a saturated solution of the sparingly soluble salt. This provides us with a method of finding the concentration of sodium carbonate or oxalate formed in the above cases and thus testing the accuracy of the supposed mechanism and also the correctness of the dependence of the reaction on the various factors enumerated above. To enable us to apply the test at least qualitatively, we have to introduce another approximation, that the solutions are sufficiently dilute so that the conductivity of a mixture might be taken equal to the sum of the conductivities of the constituents. On the basis of these assumptions, the increment in specific conductivity which may be ascribed to the sodium carbonate or oxalate formed, can be calculated easily by deducting the specific conductivity of a saturated solution of the sparingly soluble salt from the actual measured increment in the specific conductivity. In the following Table 4 is given, on the basis of the data recorded in the Table 2, this calculated increment of specific conductivity ascribed to the sodium carbonate alone formed as a result of the dissolution of calcium carbonate in a given solution of the sodium hexametaphosphate. Now, as shown above, if the reaction goes to completion, then the concentration of sodium carbonate formed would be the same as that of the sodium hexametaphosphate itself. Therefore, for comparison is given in the last column of the Table 4, the specific conductivity of a solution of sodium carbonate of the same concentration as that of the hexametaphosphate started with. The close parallelism of the figures in the last two columns of the table indicates the correctness of the assumed mechanism.

The Table 5 records the corresponding data when calcium oxalate is used in place of calcium carbonate.

TABLE 4.

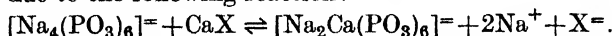
1	2	3	4	5	6
Conc. of hexametaphosphate solution.	Sp. Cond. of the solution.	Sp. Cond. when saturated with CaCO_3 .	Sp. Cond. of a saturated CaCO_3 solution.	Sp. Cond. of Na_2CO_3 formed (3—2—4).	Sp. Cond. of a Na_2CO_3 solution of the same strength as the hexametaphosphate solution.
M/128 ..	0.001454	0.002710	0.000032	0.001224	0.001423
M/256 ..	0.000796	0.001498	0.000032	0.000670	0.000824
M/512 ..	0.000430	0.000826	0.000032	0.000364	0.000436
M/1024 ..	0.000237	0.000537	0.000032	0.000266	0.000227
M/2048 ..	0.000132	0.000293	0.000032	0.000129	0.000117

TABLE 5.

1	2	3	4	5	6
Conc. of hexameta-phosphate solution.	Sp. Cond. of the solution.	Sp. Cond. when saturated with CaC_2O_4 .	Sp. Cond. of a saturated CaC_2O_4 solution.	Sp. Cond. of $\text{Na}_2\text{C}_2\text{O}_4$ formed (3—2—4).	Sp. Cond. of a $\text{Na}_2\text{C}_2\text{O}_4$ solution of the same strength as the hexameta-phosphate solution.
M/128 ..	0.001454	0.002645	0.000016	0.001175	0.001588
M/256 ..	0.000796	0.001420	0.000016	0.000608	0.000841
M/512 ..	0.000430	0.000820	0.000016	0.000374	0.000433
M/1024 ..	0.000237	0.000513	0.000016	0.000260	0.000233
M/2048 ..	0.000132	0.000280	0.000016	0.000132	0.000119

A comparison of the data in the last two columns of the Tables 4 and 5 shows that the concentration of sodium carbonate or the sodium oxalate formed as a result of the dissolution of calcium carbonate or oxalate in sodium hexameta-phosphate solutions is generally of the same order as that of the hexameta-phosphate itself. Thus, the experimental data support the assumed mechanism. The data also show that the difference between the experimental and theoretical values (columns 5 and 6) is, in the more concentrated solutions, much less in the case of calcium carbonate than in the corresponding case of calcium oxalate. A more detailed and quantitative account of these differences will be given in a subsequent communication. Moreover, a perusal of the data in the Tables 4 and 5 clearly shows that both in the case of calcium carbonate as well as oxalate, the reaction does not go to completion in the more concentrated solutions but as the dilution of the hexameta-phosphate solution is increased, the reaction goes to completion or even slightly overshoots the mark. Whether this tendency for the reaction to proceed to the second stage also in the case of calcium salts is real or is only apparent and really due to the approximations made in the present study, would be decided only on more quantitative work. However, at least the correctness of the assumption, that the solubility of the insoluble salt in moles of the salt dissolved per mole of the hexameta-phosphate increases with the dilution of the hexameta-phosphate solution, is established on the above data.

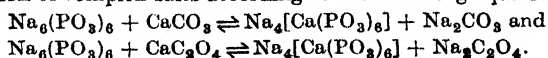
Thus, the increments in specific conductivity which the sodium hexameta-phosphate solutions exhibit when shaken to saturation with calcium carbonate or oxalate are mainly due to the following reaction:



In the following parts of this series will be published more quantitative results obtained by different physico-chemical methods to support and further elucidate the mechanism assumed above.

SUMMARY.

1. The preparation and properties of pure sodium hexameta-phosphate has been described.
2. The conductivities of the sodium hexameta-phosphate solutions have been measured and its power of forming complex ions with Ca^{++} , Sr^{++} , Ba^{++} , Pb^{++} , Mg^{++} , Be^{++} , Zn^{++} , Fe^{+++} , $(\text{UO}_2)^{++}$ and other ions has been demonstrated qualitatively.
3. A study of the mechanism of the dissolution of calcium carbonate and oxalate by the sodium hexameta-phosphate has been made by measuring the increments in specific conductivity which the solutions of sodium hexameta-phosphate exhibit when shaken to saturation with these sparingly soluble salts and from these studies, it has been concluded that the dissolution is due to the formation of complex salts according to the following equations:



REFERENCES.

- Berthelot and Andre (1897). Metaphosphoric acid. *Compt. rend.*, **124**, 265.
- Campbell and Schenker (1945). A polarographic study of barium ion removal by complex phosphates. *J. Am. Chem. Soc.*, **67**, 767.
- Graham (1833). Metaphosphates. *Phil. Trans.*, **123**, 253.
- Hall (1934, 1935). *U. S. Patent*, 1956515 and *Reissue*, 19719.
- Jawein and Thillot (1889). Molecular weight of some metaphosphates. *Ber.*, **22**, 654.
- Knorre (1892). Separation and estimation of pyro- and metaphosphoric acids. *Zeit. Angew. Chem.*, **5**, 839.
- (1900). Metaphosphates. *Zeit. anorg. Chem.*, **24**, 369.
- Ludert (1893). Hexametaphosphates. *Ibid.*, **5**, 15.
- Pascal (1923). Hexametaphosphates. *Compt. rend.*, **177**, 1298.
- (1924). Insoluble alkali metaphosphates. *Compt. rend.*, **178**, 211; **178**, 1541.
- (1924). Transformation of polymetaphosphates. *Compt. rend.*, **178**, 1906.
- (1924). Metaphosphates. *Bull. Soc. Chim.*, (iv), **35**, 1131.
- Rosenstein (1936). *U. S. Patent*, 2038316.
- Stelling and Frang (1941). Alkali meta-, pyro-, and poly-phosphates, I. *Svensk Kem. Tidskr.*, **53**, 290; *British abstracts*, Nov., 1947, AI, 327.
- Tamman (1890). Isomerisation of metaphosphates. *Zeit. physikal. Chem.*, **6**, 122.
- (1892). Metaphosphates. *J. prakt. Chem.*, (2), **45**, 417.
- Tantar (1898). Metaphosphoric acids. *J. Russ. Chem. Soc.*, **30**, 99.
- Thomson (1936). Properties of sodium hexametaphosphate. *Analyst*, **61**, 320.
- Treadwell and Leutwyler (1938). Constitution and analysis of polymeric phosphoric acids. *Helv. Chim. Acta*, **21**, 1450.

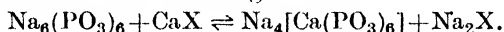
STUDIES IN HEXAMETAPHOSPHATES: PART II.

A STUDY OF THE COMPLEXES FORMED BY SODIUM HEXAMETAPHOSPHATE WITH STRONTIUM, BARIUM AND LEAD IONS BY CONDUCTIVITY DATA.

By R. C. MEHROTRA and N. R. DHAR, Chemical Laboratories, The University of Allahabad, Allahabad.

(Received October 10; read November 25, 1949.)

In an earlier communication (Mehrotra and Dhar, 1949), it has been shown that when sodium hexametaphosphate solutions are shaken with sparingly soluble salts of calcium, then the mixture shows an appreciable increment in specific conductivity. From the order of the increments in specific conductivities, it has been concluded that the dissolution of insoluble calcium salts in sodium hexametaphosphate solutions is due to the following reaction:



The extent to which the reaction proceeds forward has been shown to depend upon (1) the instability constant of the complex ion formed, (2) the solubility product of the sparingly soluble salt used, and (3) the dilution of the hexametaphosphate solution.

The present communication records the results of similar investigations carried out with the sparingly soluble salts—sulphates of strontium, barium and lead.

EXPERIMENTAL.

Sodium hexametaphosphate solutions were prepared as described in the earlier communication and after measuring their specific conductivity, the solutions were shaken with strontium sulphate, barium sulphate and lead sulphate. The mixtures were shaken vigorously from time to time and were allowed to stand at the room temperature. The specific conductivities of the mixtures were measured on successive days and when the conductivities did not show a variation greater than 1 to 2%, the values were taken as constant. It was observed that the solutions of hexametaphosphate became saturated with strontium and lead sulphates in about 3–4 days, but it took about 6 to 7 days for the solution to get saturated with barium sulphate.

TABLE 1.

Specific conductivities at 22.5° C. of sodium hexametaphosphate solutions when alone and when saturated with strontium sulphate.

Conc. of sodium hexametaphosphate solution.	Specific Conductivity of the hexametaphosphate solution alone.	Specific Conductivity of the solution when shaken with strontium sulphate.
M/64 ..	0.002486	0.004731
M/128 ..	0.001322	0.002910
M/256 ..	0.000746	0.001772
M/512 ..	0.000403	0.001070
M/1024 ..	0.000213	0.000613
Water ..	1.2×10^{-6}	0.000140

TABLE 2.

Specific conductivities at 30.0° C. of sodium hexametaphosphate solutions when alone and when saturated with strontium sulphate.

Conc. of sodium hexametaphosphate solution.	Specific Conductivity of the hexametaphosphate solution alone.	Specific Conductivity of the solution when shaken with strontium sulphate.
M/32 ..	0.005966	0.00946
M/64 ..	0.003220	0.005970
M/128 ..	0.001740	0.003540
M/256 ..	0.000964	0.002090
M/512 ..	0.000507	0.001162
M/1024 ..	0.000276	0.000751
Water ..	1.3×10^{-6}	0.000171

TABLE 3.

Specific conductivities at 22.5° C. of sodium hexametaphosphate solutions when alone and when saturated with lead sulphate.

Conc. of sodium hexametaphosphate solution.	Specific Conductivity of the hexametaphosphate solution alone.	Specific Conductivity of the solution when shaken with lead sulphate.
M/64 ..	0.002486	0.004981
M/128 ..	0.001322	0.002990
M/256 ..	0.000746	0.001767
M/512 ..	0.000403	0.001198
M/1024 ..	0.000213	0.000652
Water ..	1.2×10^{-6}	0.000051

TABLE 4.

Specific conductivities at 20.0° C. of sodium hexametaphosphate solutions when alone and when saturated with lead sulphate.

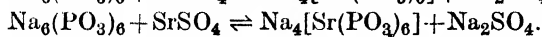
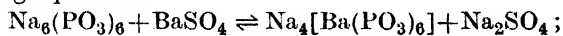
Conc. of sodium hexametaphosphate solution.	Specific Conductivity of the hexametaphosphate solution alone.	Specific Conductivity of the solution when shaken with lead sulphate.
M/128 ..	0.001291	0.002880
M/256 ..	0.000710	0.001662
M/512 ..	0.000384	0.001170
M/1024 ..	0.000204	0.000639
Water ..	1.3×10^{-6}	0.000044

TABLE 5.

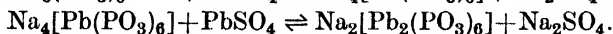
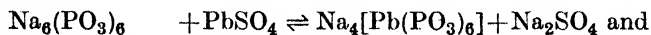
Specific conductivities at 22.5° C. of sodium hexametaphosphate solutions when alone and when saturated with barium sulphate.

Conc. of sodium hexametaphosphate solution.	Specific Conductivity of the hexametaphosphate solution alone.	Specific Conductivity of the solution when shaken with barium sulphate.
M/64 ..	0.002486	0.003031
M/128 ..	0.001322	0.001823
M/256 ..	0.000746	0.001242
M/512 ..	0.000403	0.000788
M/1024 ..	0.000213	0.000439
Water ..	1.2×10^{-6}	7.3×10^{-6}

A perusal of the conductivity data in the Tables 1 to 5 shows that the main reaction in the case of strontium and barium sulphates might be represented by the following equations:



However, as discussed in the earlier communication, the reaction goes forward to a greater extent in the case of strontium sulphate (solubility product = 2.8×10^{-7}) than in the case of barium sulphate (solubility product = 1.2×10^{-10}). Moreover, in every case the reaction goes forward to a greater extent as the dilution of the hexametaphosphate solution is increased. In the case of lead sulphate, however, the reaction has a tendency to go to a stage further as represented by the following equations:



Further work has confirmed the mechanism assumed above.

SUMMARY.

1. The conductivities of solutions of sodium hexametaphosphate of varying strengths have been measured first alone and when saturated with sulphates of strontium, barium and lead.
2. It has been observed that the specific conductivities shows a very large increment when the solutions are shaken with these insoluble salts.
3. From the order of these increments in specific conductivities, it has been concluded that the strontium, barium and lead sulphates dissolve in the sodium hexametaphosphate solutions with the formation of the complex salts— $\text{Na}_4\text{Sr}(\text{PO}_3)_6$, $\text{Na}_4\text{Ba}(\text{PO}_3)_6$ and $\text{Na}_4\text{Pb}(\text{PO}_3)_6$. However only in the case of lead, there is a marked tendency of the reaction to go to a stage further with the formation of the complex— $\text{Na}_2\text{Pb}_2(\text{PO}_3)_6$.

REFERENCES.

- Mehrotra and Dhar (1949). Preparation and properties of sodium hexametaphosphate and a study of the extent of complex formation with calcium ions by conductivity data. *Proc. Nat. Inst. Sci. Ind.*, **16**, 59.

ON THE NÖRLUND SUMMABILITY OF DERIVED FOURIER SERIES.

By B. N. PRASAD and J. A. SIDDIQI.

(Received May 31; read August 5, 1949.)

1.1. Let $f(x)$ be a function integrable in the sense of Lebesgue and periodic of period 2π . Let the Fourier series associated with $f(x)$ be

$$\frac{1}{2}a_0 + \sum_{n=1}^{\infty} (a_n \cos nx + b_n \sin nx). \quad \dots \quad \dots \quad \dots \quad (1)$$

The derived series of the Fourier series is

$$\sum_{n=1}^{\infty} n(b_n \cos nx - a_n \sin nx). \quad \dots \quad \dots \quad \dots \quad (2)$$

It is well known that the derived series may not itself be a Fourier series.

The (C, r) summability of the series (2) corresponding to a function $f(x)$ of bounded variation has been considered by Young (1914) and M. Riesz (1923). They have proved:

A. The derived series corresponding to a function $f(x)$ of bounded variation is summable (C, r) , $0 < r \leq 1$ to $f'(x)$ at the point x for which

$$\chi_0(t) = \int_0^t |d_s \chi(s)| = o(t),$$

where $\chi(t) = f(x+t) - f(x-t) - 2t f'(x)$, i.e. for almost every x .

Hille and Tamarkin (1932) have extended the scope of this theorem by applying to the derived series the method of Nörlund summability which, as known, includes, as special cases, the method of Cesàro summability.

If we remove the restriction that $f(x)$ is of bounded variation in $(-\pi, \pi)$, then the theorem A as well as that of Hille and Tamarkin break down. The (C, r) summability of derived series when $f(x)$ is not necessarily a function of bounded variation, has been considered by Lebesgue (1905), Privaloff (1919), and Young (1914). They have proved the following theorem:

B. At every point x , where

$$f'(x) = \lim_{h \rightarrow 0} \frac{f(x+h) - f(x-h)}{2h}$$

exists and is finite, the derived series (2) is summable (C, r) , $r > 1$, to the value $f'(x)$.

The corresponding result for the case of Nörlund summability has been obtained by Astrachan (1936) who proved:

C. A regular Nörlund method of summation (N, p_n) sums the series (2) to $f'(x)$ at all the points at which

$$f'(x) = \lim_{h \rightarrow 0} \frac{f(x+h) - f(x-h)}{2h}$$

exists and is finite, if the generating sequence (p_n) satisfies the following conditions:—

- (i) $n^j |\Delta^{j-1} p_n| = O(P_n) \quad (j = 1, 2);$
- (ii) $\sum_{k=1}^n k^{j-m-1} (n-k)^m |\Delta^{j-1} p_k| = O(P_n) \quad (j = 1, 2, 3; m = 0, 1);$
- (iii) $\sum_{k=1}^n \frac{|P_k|}{k^2} = O\left(\frac{P_n}{n}\right).$

The theorem B has been still more generalized by Chen (1929) who has established the following theorem:

D. At every point x , where

$$\chi_0(t) = \int_0^t u^{-1} |\chi(u)| du = o(t),$$

where $\chi(t) \equiv f(x+t) - f(x-t) - 2t f'(x)$, the series (2) is summable (C, r) , $r > 1$ to the value $f'(x)$.

The object of this paper is to extend still further the scope of summability of the derived Fourier series by applying the more general method of Nörlund summability. We prove the following:

THEOREM. A regular Nörlund method of summation (N, p_n) sums the derived series,

$$\sum_{n=1}^{\infty} n(b_n \cos nx - a_n \sin nx)$$

to $f'(x)$ at every point x at which

$$\dot{\chi}_0(t) = \int_0^t u^{-1} |\chi(u)| du = o(t),$$

where $\chi(t) \equiv f(x+t) - f(x-t) - 2tf'(x)$, if the generating sequence (p_n) satisfies the following conditions:—

- (I) $\sum_{k=1}^n |\Delta p_k| = O\left(\frac{P_n}{n}\right);$
- (II) $\sum_{k=1}^n k |\Delta^2 p_k| = O\left(\frac{P_n}{n}\right);$
- (III) $\sum_{k=1}^n \frac{|P_k|}{k^2} = O\left(\frac{P_n}{n}\right).$

It is evident that this theorem includes the previous theorems B, C and D.

1.2. In § 2.1 to § 2.3, we give the main proof of the theorem. It will be noted that this proof involves the help of a number of results whose proof, for the sake of convenience, will be given separately in the shape of lemmas.

2.1. **PROOF.** In what follows we shall suppose that the sequence (p_n) satisfies the conditions (I) to (III) of the above theorem.

The k th term of the series (2) is

$$\frac{1}{\pi} \int_0^\pi \{f(x+t) - f(x-t)\} k \sin kt \, dt,$$

and hence the n th generalized regular * Nörlund mean is

$$\begin{aligned} N'_n \left[f(x), p_n \right] &= \frac{1}{\pi} \int_0^\pi \{f(x+t) - f(x-t)\} \cdot \frac{1}{P_n} \sum_{k=0}^n P_{n-k} (k \sin kt) \, dt \\ &= \frac{1}{\pi} \int_0^\pi \chi(t) \cdot \frac{1}{P_n} \sum_{k=0}^n P_{n-k} (k \sin kt) \, dt \\ &\quad + \frac{2f'(x)}{\pi} \int_0^\pi t \cdot \frac{1}{P_n} \sum_{k=0}^n P_{n-k} (k \sin kt) \, dt. \end{aligned}$$

Now

$$\begin{aligned} &\int_0^\pi t \cdot \frac{1}{P_n} \sum_{k=0}^n P_{n-k} (k \sin kt) \, dt \\ &= \left[\frac{t}{P_n} \sum_{k=0}^n P_{n-k} (-\cos kt) \right]_0^\pi + \int_0^\pi \frac{1}{P_n} \sum_{k=0}^n P_{n-k} \cos kt \, dt \\ &= -\frac{\pi}{P_n} \sum_{k=0}^n P_{n-k} (-1)^k + \pi + \int_0^\pi \frac{1}{P_n} \sum_{k=0}^n P_{n-k} \cos kt \, dt \\ &= -\frac{\pi}{P_n} \sum_{k=0}^n p_{n-k} \frac{1 - (-1)^{k+1}}{2} + \pi + \left[\frac{1}{P_n} \sum_{k=1}^n P_{n-k} \frac{\sin kt}{k} \right]_0^\pi + o(1) \\ &= \frac{\pi}{2} - \frac{\pi}{2} \frac{(-1)^n}{P_n} \sum_{k=0}^n p_k (-1)^k + o(1) \\ &= \frac{\pi}{2} + o(1), \end{aligned}$$

since

$$\sum_{k=0}^n p_k (-1)^k = o(P_n) \text{ and } |P_n| \rightarrow \infty,$$

by virtue of lemmas 1 and 2.

Hence

$$N'_n \left[f(x), p_n \right] - f'(x) = \frac{1}{\pi} \int_0^\pi \chi(t) \cdot \frac{1}{P_n} \sum_{k=0}^n P_{n-k} (k \sin kt) \, dt + o(1).$$

* A Nörlund method of summation (N, p_n) is said to be *regular* if the following conditions are satisfied:

- (i) $p_n = o(P_n)$, (ii) $\sum_{k=0}^n |p_k| = O(P_n)$.

In order to prove the theorem we have to show that the right-hand side integral is $o(1)$, as $n \rightarrow \infty$, under the conditions of the theorem.

Putting

$$N_n(t) = \frac{1}{\pi P_n} \sum_{k=0}^n P_{n-k} \cos kt,$$

we get

$$\begin{aligned} L &= \frac{1}{\pi} \int_0^\pi \chi(t) \frac{1}{P_n} \sum_{k=0}^n P_{n-k} k \sin kt \, dt \\ &= - \int_0^\pi \chi(t) N'_n(t) \, dt \\ &= - \left(\int_0^{\frac{1}{n}} + \int_{\frac{1}{n}}^\delta + \int_\delta^\pi \right) \chi(t) \cdot N'_n(t) \, dt \\ &= -(L_1 + L_2 + L_3), \quad \text{say.} \end{aligned}$$

2.2. Now

$$\begin{aligned} L_1 &= \int_0^{n^{-1}} t^{-1} \chi(t) \cdot t N'_n(t) \, dt \\ &= O \left(\int_0^{n^{-1}} t^{-1} |\chi(t)| \cdot |t N'_n(t)| \, dt \right) \\ &= O \left(n \int_0^{n^{-1}} t^{-1} |\chi(t)| \, dt \right) \\ &= O(n \chi_0(n^{-1})) \\ &= o(1), \quad \text{as } n \rightarrow \infty, \end{aligned}$$

since $t N'_n(t) = O(n)$, for all t such that $0 \leq t \leq n^{-1}$.

It is known that (Astrachan, 1936)

$$t N'_n(t) = o(1)$$

uniformly in t for $0 < \delta \leq |t| \leq \pi$, where δ is fixed, provided

$$(i) \quad |\Delta^{j-1} p_n| = o(P_n) \quad (j = 1, 2),$$

$$(ii) \quad \sum_{k=0}^n (n-k)^\beta |\Delta^2 p_k| = o(P_n) \quad (\beta = 0, 1).$$

Hence we have

$$\begin{aligned} L_3 &= \int_{\delta}^{\pi} t^{-1} \chi(t) \cdot t N'_n(t) dt \\ &= o \left(\int_{\delta}^{\pi} |t^{-1} \chi(t)| dt \right) \\ &= o(1), \text{ as } n \rightarrow \infty. \end{aligned}$$

2.3. It remains to show that $L_2 = o(1)$, as $n \rightarrow \infty$. To prove this we require a suitable estimate for $t N'_n(t)$ in the interval (n^{-1}, δ) . We make use of the following notations:

$$\begin{aligned} |p_n| &= r_n, \quad R_n = r_0 + r_1 + \dots + r_n; \\ r(u) &= r_{[u]}, \quad R(u) = R_{[u]}, \end{aligned}$$

where $[u]$ denotes the largest integer $\leq u$;

$$W^{\beta}(m) = \sum_{k=0}^m (n-k)^{\beta} |\Delta^2 p_k|; \quad \tau = [t^{-1}].$$

We have (Astrachan, 1936)

$$|t N'_n(t)| \leq A \sum_{m=1}^4 M_{nm}(t) \quad \text{for } n^{-1} \leq t \leq \delta,$$

where

$$\begin{aligned} M_{n1}(t) &= \frac{1}{R(n)} \sum_{\beta=0}^1 n^{\beta} t^{\beta-1} R(t^{-1}), \\ M_{n2}(t) &= \frac{1}{R(n)} \sum_{j=1}^2 \sum_{\beta=0}^1 (n-\tau)^{\beta} t^{\beta-j-1} |\Delta^{j-1} p_{\tau}|, \\ M_{n3}(t) &= \frac{1}{R(n)} \sum_{j=1}^2 t^{-j-1} |\Delta^{j-1} p_n|, \\ M_{n4}(t) &= \frac{1}{R(n)} \sum_{\beta=0}^1 t^{\beta-3} \{W^{\beta}(n) - W^{\beta}(t^{-1})\}. \end{aligned}$$

Now we have

$$\begin{aligned} L_2 &= \int_{n^{-1}}^{\delta} t^{-1} \chi(t) \cdot t N'_n(t) dt \\ &= O \left(\int_{n^{-1}}^{\delta} t^{-1} |\chi(t)| \cdot |t N'_n(t)| dt \right) \end{aligned}$$

$$\begin{aligned}
&= O\left(\int_{n-1}^{\delta} t^{-1} |\chi(t)| \cdot \sum_{m=1}^4 M_{nm}(t) dt\right) \\
&= O\left(\int_{n-1}^{\delta} t^{-1} |\chi(t)| M_{n1}(t) dt\right) + O\left(\int_{n-1}^{\delta} t^{-1} |\chi(t)| M_{n2}(t) dt\right) \\
&\quad + O\left(\int_{n-1}^{\delta} t^{-1} |\chi(t)| M_{n3}(t) dt\right) + O\left(\int_{n-1}^{\delta} t^{-1} |\chi(t)| M_{n4}(t) dt\right) \\
&= O(L_{21}) + O(L_{22}) + O(L_{23}) + O(L_{24}), \quad \text{say.}
\end{aligned}$$

Now

$$\begin{aligned}
L_{21} &= \int_{n-1}^{\delta} t^{-1} |\chi(t)| \cdot \frac{1}{R(n)} \sum_{\beta=0}^1 n^{\beta} t^{-1+\beta} R(t^{-1}) dt \\
&= \int_{n-1}^{\delta} t^{-1} |\chi(t)| \frac{R(t^{-1})}{tR(n)} dt + \int_{n-1}^{\delta} t^{-1} |\chi(t)| \frac{nR(t^{-1})}{R(n)} dt \\
&= \left[\chi_0(t) \frac{R(t^{-1})}{nR(n)} \right]_{n-1}^{\delta} - \frac{1}{R(n)} \int_{n-1}^{\delta} \chi_0(t) \frac{dR(t^{-1})}{t} + \frac{1}{R(n)} \int_{n-1}^{\delta} \chi_0(t) R(t^{-1}) \frac{dt}{t^2} \\
&\quad + \left[\chi_0(t) \frac{nR(t^{-1})}{R(n)} \right]_{n-1}^{\delta} - \frac{n}{R(n)} \int_{n-1}^{\delta} \chi_0(t) dR(t^{-1}) \\
&= O\left(\frac{1}{R(n)}\right) + O(n\chi_0(n^{-1})) + o\left(\frac{1}{R(n)} \int_{n-1}^{\delta} |dR(t^{-1})| \right) + o\left(\frac{1}{R(n)} \int_{n-1}^{\delta} R(t^{-1}) \frac{dt}{t}\right) \\
&\quad + O\left(\frac{n}{R(n)}\right) + o\left(\frac{n}{R(n)} \int_{n-1}^{\delta} t |dR(t^{-1})| \right) \\
&= O\left(\frac{n}{R(n)}\right) + o\left(\frac{1}{R(n)} \int_1^n |dR(s)| \right) + o\left(\frac{1}{R(n)} \int_1^n \frac{R(s)}{s} ds\right) \\
&\quad + o\left(\frac{n}{R(n)} \int_1^n \frac{|dR(s)|}{s}\right) + o(1) \\
&= O\left(\frac{n}{|P_n|}\right) + o\left(\frac{1}{|P_n|} \sum_{k=0}^n |p_k|\right) + o\left(\frac{1}{|P_n|} \sum_{k=1}^n \frac{|P_k|}{k}\right) + o\left(\frac{n}{|P_n|} \sum_{k=1}^n \frac{|p_k|}{k}\right) \\
&\quad + o(1). \\
&= O\left(\frac{n}{|P_n|}\right) + o(1) + o\left(\frac{n}{|P_n|} \sum_{k=1}^n \frac{|P_k|}{k^2}\right) + o\left(\frac{n}{|P_n|} \sum_{k=1}^n \frac{|p_k|}{k}\right) + o(1),
\end{aligned}$$

the second term on the right being $o(1)$ by virtue of regularity condition.

Now we have

$$n = o(P_n) \quad \text{by virtue of lemma 2;}$$

$$\sum_{k=1}^n \frac{|P_k|}{k^2} = O\left(\frac{P_n}{n}\right) \quad \text{by virtue of condition (III) of the theorem;}$$

$$o\left(\frac{n}{|P_n|} \cdot \sum_{k=1}^n \frac{|p_k|}{k}\right) = o\left(\frac{n}{|P_n|} \sum_{k=1}^n \frac{|P_k|}{k^2}\right) = o(1) \quad \text{by virtue of lemma 3 and the condition (III) of the theorem.}$$

Hence

$$L_{21} = o(1).$$

Again

$$\begin{aligned} L_{22} &= \int_{n-1}^{\delta} t^{-1} |\chi(t)| \cdot \frac{1}{R(n)} \sum_{j=1}^2 \sum_{\beta=0}^1 (n-\tau)^{\beta} t^{\beta-j-1} |\Delta^{j-1} p_{\tau}| dt \\ &= \left[\chi_0(t) \cdot \frac{1}{R(n)} \sum_{j=1}^2 \sum_{\beta=0}^1 (n-\tau)^{\beta} t^{\beta-j-1} |\Delta^{j-1} p_{\tau}| \right]_{n-1}^{\delta} \\ &\quad - \int_{n-1}^{\delta} \chi_0(t) \cdot \frac{1}{R(n)} \sum_{j=1}^2 \sum_{\beta=0}^1 (\beta-j-1)(n-\tau)^{\beta} t^{\beta-j-2} |\Delta^{j-1} p_{\tau}| dt \\ &\quad - \int_{n-1}^{\delta} \chi_0(t) \cdot \frac{1}{R(n)} \sum_{j=1}^2 \sum_{\beta=0}^1 (n-\tau)^{\beta} t^{\beta-j-1} d |\Delta^{j-1} p_{\tau}| \\ &\quad + \int_{n-1}^{\delta} \chi_0(t) \cdot \frac{1}{R(n)} \sum_{j=1}^2 \sum_{\beta=0}^1 \beta \cdot t^{\beta-j-1} |\Delta^{j-1} p_{\tau}| d\tau \\ &= O\left(\frac{1}{R(n)} \sum_{j=1}^2 \sum_{\beta=0}^1 n^{\beta}\right) + o\left(\frac{1}{R(n)} \sum_{j=1}^2 n^j |\Delta^{j-1} p_n|\right) \\ &\quad + o\left(\frac{1}{R(n)} \int_{n-1}^{\delta} \sum_{j=1}^2 \sum_{\beta=0}^1 (n-\tau)^{\beta} t^{\beta-j-1} |\Delta^{j-1} p_{\tau}| dt\right) \\ &\quad + o\left(\frac{1}{R(n)} \int_{n-1}^{\delta} \sum_{j=1}^2 \sum_{\beta=0}^1 (n-\tau)^{\beta} t^{\beta-j} d |\Delta^{j-1} p_{\tau}|\right) \\ &\quad + o\left(\frac{1}{R(n)} \int_{n-1}^{\delta} \sum_{j=1}^2 t^{1-j} |\Delta^{j-1} p_{\tau}| d\tau\right) \end{aligned}$$

$$\begin{aligned}
&= O\left(\frac{n}{R(n)}\right) + o\left(\frac{1}{R(n)} \sum_{j=1}^2 n^j |\Delta^{j-1} p_n|\right) \\
&\quad + o\left(\frac{1}{R(n)} \int_1^n \sum_{j=1}^2 \sum_{\beta=0}^1 (n-[s])^\beta s^{j-\beta-1} |\Delta^{j-1} p_{[s]}| ds\right) \\
&\quad + o\left(\frac{1}{R(n)} \int_1^n \sum_{j=1}^2 \sum_{\beta=0}^1 s^{j-\beta} (n-[s])^\beta d |\Delta^{j-1} p_{[s]}|\right) \\
&\quad + o\left(\frac{1}{R(n)} \int_1^n \sum_{j=1}^2 s^{j-1} |\Delta^{j-1} p_{[s]}| ds\right) \\
&= O\left(\frac{n}{|P_n|}\right) + o\left(\frac{1}{|P_n|} \sum_{j=1}^2 n^j |\Delta^{j-1} p_n|\right) \\
&\quad + o\left(\sum_{j=1}^2 \sum_{\beta=0}^1 \frac{1}{|P_n|} \sum_{k=1}^n k^{j-\beta-1} (n-k)^\beta |\Delta^{j-1} p_k|\right) \\
&\quad + o\left(\sum_{j=1}^2 \sum_{\beta=0}^1 \frac{1}{|P_n|} \sum_{k=1}^n k^{j-\beta} (n-k)^\beta |\Delta^j p_k|\right) \\
&\quad + o\left(\sum_{j=1}^2 \frac{1}{|P_n|} \sum_{k=1}^n k^{j-1} |\Delta^{j-1} p_k|\right) \\
&= O\left(\frac{n}{|P_n|}\right) + o\left(\frac{n^2 |\Delta p_n|}{|P_n|}\right) + o\left(\frac{n |p_n|}{|P_n|}\right) \\
&\quad + o\left(\sum_{j=0}^2 \sum_{\beta=0}^1 \frac{1}{|P_n|} \sum_{k=1}^n k^{j-\beta} (n-k)^\beta |\Delta^j p_k|\right).
\end{aligned}$$

Now we show that each term on the right in the above is $o(1)$. We have

$$\begin{aligned}
n &= o(P_n), \quad \text{by virtue of lemma 2;} \\
n |p_n| &= O(P_n) \quad \text{from lemma 3;} \\
n^2 |\Delta p_n| &= O(P_n) \quad \text{from lemma 5.}
\end{aligned}$$

We shall now show that

$$\sum_{k=1}^n k^{j-\beta} (n-k)^\beta |\Delta^j p_k| = O(P_n) \quad (\beta = 0, 1; j = 0, 1, 2).$$

Breaking the summation on the left in six parts, we have

$$\begin{aligned}
(a) \quad \sum_{k=1}^n |p_k| &= O(P_n), & (b) \quad \sum_{k=1}^n k |\Delta p_k| &= O(P_n),
\end{aligned}$$

$$\begin{aligned}
 (c) \quad \sum_{k=1}^n k^2 |\Delta^2 p_k| &= O(P_n), & (d) \quad \sum_{k=1}^n k^{-1}(n-k) |p_k| &= O(P_n), \\
 (e) \quad \sum_{k=1}^n (n-k) |\Delta p_k| &= O(P_n), & (f) \quad \sum_{k=1}^n k(n-k) |\Delta^2 p_k| &= O(P_n).
 \end{aligned}$$

For, (a) follows from regularity condition, (b) and (e) from condition (I), and (c) and (f) from condition (II) of the theorem, and finally

$$\begin{aligned}
 \sum_{k=1}^n k^{-1}(n-k) |p_k| &= \sum_{k=1}^n n \cdot \frac{|p_k|}{k} - \sum_{k=1}^n |p_k| \\
 &\leq C \sum_{k=1}^n \frac{n|p_k|}{k^2} - \sum_{k=1}^n |p_k| \\
 &= O(P_n),
 \end{aligned}$$

by virtue of regularity condition, lemma 3, and condition (III) of the theorem.

Hence

$$L_{22} = o(1).$$

Similarly,

$$\begin{aligned}
 L_{23} &= \int_{n-1}^{\delta} t^{-1} |\chi(t)| \cdot \frac{1}{R(n)} \sum_{j=1}^2 t^{-j-1} |\Delta^{j-1} p_n| dt \\
 &= \left[\chi_0(t) \frac{1}{R(n)} \sum_{j=1}^2 t^{-j-1} |\Delta^{j-1} p_n| \right]_{n-1}^{\delta} \\
 &\quad + (j+1) \int_{n-1}^{\delta} \chi_0(t) \cdot \frac{1}{R(n)} \sum_{j=1}^2 t^{-j-2} |\Delta^{j-1} p_n| dt \\
 &= O\left(\frac{1}{R(n)} \sum_{j=1}^2 |\Delta^{j-1} p_n|\right) + o\left(\frac{1}{R(n)} \sum_{j=1}^2 n^j |\Delta^{j-1} p_n|\right) \\
 &\quad + o\left(\int_{n-1}^{\delta} \frac{1}{R(n)} \sum_{j=1}^2 t^{-j-1} |\Delta^{j-1} p_n| dt\right) \\
 &= O\left(\frac{1}{R(n)} \sum_{j=1}^2 |\Delta^{j-1} p_n|\right) + o\left(\frac{1}{R(n)} \sum_{j=1}^2 n^j |\Delta^{j-1} p_n|\right) \\
 &\quad + o\left(\left[\frac{1}{R(n)} \sum_{j=1}^2 |\Delta^{j-1} p_n| t^{-j}\right]_{n-1}^{\delta}\right) \\
 &= O\left(\frac{1}{R(n)} \sum_{j=1}^2 |\Delta^{j-1} p_n|\right) + o\left(\frac{1}{R(n)} \sum_{j=1}^2 n^j |\Delta^{j-1} p_n|\right)
 \end{aligned}$$

Now

$|\Delta^{j-1}p_n| = o(P_n)$ ($j = 1, 2$) by virtue of regularity condition ;

$n |p_n| = O(P_n)$ from lemma 3 ;

and $n^2 |\Delta p_n| = O(P_n)$ follows from lemma 5.

Hence

$$L_{23} = o(1).$$

Finally,

$$\begin{aligned} L_{24} &= \int_{n-1}^{\delta} t^{-1} |\chi(t)| \cdot \frac{1}{R(n)} \sum_{\beta=0}^1 t^{\beta-3} \{W^{\beta}(n) - W^{\beta}(t^{-1})\} dt \\ &= \left[\chi_0(t) \frac{1}{R(n)} \sum_{\beta=0}^1 t^{\beta-3} \{W^{\beta}(n) - W^{\beta}(t^{-1})\} \right]_{n-1}^{\delta} \\ &\quad - (\beta-3) \int_{n-1}^{\delta} \chi_0(t) \frac{1}{R(n)} \sum_{\beta=0}^1 t^{\beta-4} \{W^{\beta}(n) - W^{\beta}(t^{-1})\} dt \\ &\quad + \int_{n-1}^{\delta} \chi_0(t) \cdot \frac{1}{R(n)} \sum_{\beta=0}^1 t^{\beta-3} dW^{\beta}(t^{-1}) \\ &= O\left(\frac{1}{R(n)} \sum_{\beta=0}^1 W^{\beta}(n)\right) \\ &\quad + o\left(\int_{n-1}^{\delta} \frac{1}{R(n)} \sum_{\beta=0}^1 t^{\beta-3} \{W^{\beta}(n) - W^{\beta}(t^{-1})\} dt\right) \\ &\quad + o\left(\int_{n-1}^{\delta} \frac{1}{R(n)} \sum_{\beta=0}^1 t^{\beta-2} dW^{\beta}(t^{-1})\right) \\ &= O\left(\frac{1}{R(n)} \sum_{\beta=0}^1 W^{\beta}(n)\right) + o\left(\int_1^n \frac{1}{R(n)} \sum_{\beta=0}^1 s^{-\beta+1} \{W^{\beta}(n) - W^{\beta}(s)\} ds\right) \\ &\quad + o\left(\int_1^n \frac{1}{R(n)} \sum_{\beta=0}^1 s^{2-\beta} dW^{\beta}(s)\right) \end{aligned}$$

Now

$$\begin{aligned} \int_1^n \frac{1}{R(n)} \sum_{\beta=0}^1 s^{1-\beta} \{W^{\beta}(n) - W^{\beta}(s)\} ds &= \left[\frac{1}{R(n)} \sum_{\beta=0}^1 \frac{s^{2-\beta}}{2-\beta} \cdot \{W^{\beta}(n) - W^{\beta}(s)\} \right]_1^n \\ &\quad + \int_1^n \frac{1}{R(n)} \sum_{\beta=0}^1 \frac{s^{2-\beta}}{2-\beta} dW^{\beta}(s) \end{aligned}$$

$$= O\left(\frac{1}{R(n)} \sum_{\beta=0}^1 W^{\beta}(n)\right) + O\left(\int_1^n \frac{1}{R(n)} \sum_{\beta=0}^1 s^{2-\beta} dW^{\beta}(s)\right).$$

Hence

$$L_{24} = O\left(\frac{1}{R(n)} \sum_{\beta=0}^1 W^{\beta}(n)\right) + o\left(\int_1^n \frac{1}{R(n)} \sum_{\beta=0}^1 s^{2-\beta} dW^{\beta}(s)\right)$$

Now

$$\sum_{k=1}^n (n-k)^{\beta} |\Delta^2 p_k| = o(P_n) \quad (\beta = 0, 1) \text{ by lemma 1 ;}$$

and

$$\sum_{k=1}^n k^{2-\beta} (n-k)^{\beta} |\Delta^2 p_k| = O(P_n) \quad (\beta = 0, 1) \text{ follows from condition (II).}$$

Hence

$$L_{24} = o(1).$$

Combining the above results we obtain

$$L_2 = o(1), \text{ as } n \rightarrow \infty.$$

This completes the proof of the theorem.

3.1. LEMMAS. We now give the lemmas which have been utilised in establishing the theorem :

$$\text{Lemma 1. If } \sum_{k=1}^n k |\Delta^2 p_k| = O\left(\frac{P_n}{n}\right) \text{ and } \sum_{k=1}^n \frac{|P_k|}{k^2} = O\left(\frac{P_n}{n}\right), \text{ then}$$

$$\sum_{k=0}^n (n-k)^{\beta} |\Delta^2 p_k| = o(P_n) \text{ for } \beta = 0, 1.$$

Proof: The case for $\beta = 0$ follows directly from the condition

$$\sum_{k=1}^n k |\Delta^2 p_k| = O\left(\frac{P_n}{n}\right).$$

The case for $\beta = 1$ follows from a corresponding result of Astrachan (1936).

Lemma 2. Under conditions (II) and (III) of the theorem,

$$n = o(P_n).$$

Proof: From lemma 1 it follows that

$$\sum_{k=1}^n (n-k) |\Delta^2 p_k| = o(P_n),$$

from which, by taking the case $k = 1$, the result can easily be deduced.

Lemma 3. If $\sum_{k=1}^n k |\Delta p_k| = O(P_n)$, then $n |p_n| = O(P_n)$.

$$\text{Proof:} \quad P_k = (k+1)p_k + \sum_{j=1}^k j(p_{j-1} - p_j)$$

$$\therefore \quad (k+1)p_k = P_k + \sum_{j=1}^k j(p_j - p_{j-1})$$

$$(n+1)p_n = P_n + \sum_{j=1}^n j(\Delta p_j) = O\left\{|P_n| + \sum_{j=1}^n j |\Delta p_j|\right\} = O(P_n).$$

Hence $n |p_n| = O(P_n)$.

Lemma 4. If $\sum_{k=1}^n |\Delta p_k| = O\left(\frac{P_n}{n}\right)$, then $\sum_{k=1}^n p_k (-1)^k = o(P_n)$.

Proof: See Hille and Tamarkin (1932).

Lemma 5. If $\sum_{k=1}^n |\Delta p_k| = O\left(\frac{P_n}{n}\right)$ and $\sum_{k=1}^n k |\Delta^2 p_k| = O\left(\frac{P_n}{n}\right)$,

then $n^2 |\Delta p_n| = O(P_n)$.

$$\text{Proof:} \quad n^2 \Delta p_n = n \sum_{k=0}^{n-1} (\Delta p_k) + n \sum_{k=1}^n k (\Delta^2 p_k)$$

$$\therefore \quad n^2 |\Delta p_n| = O\left\{n \sum_{k=0}^{n-1} |\Delta p_k| + n \sum_{k=1}^n k |\Delta^2 p_k|\right\} \\ = O(P_n).$$

REFERENCES

- Astrachan, Max (1936). Studies in the summability of Fourier series by Nörlund means. *Duke Mathematical Journal*, **2**, 287-303.
- Chen, K. K. (1929). On the summability of the derived series of Fourier series. *Tohoku Math. Journal*, **31**, 62-67.
- Hille, E. and Tamarkin, J. D. (1932). On the summability of Fourier series I. *Trans. Amer. Math. Soc.*, **34**, 757-783.
- Lebesgue, H. (1905). Recherches sur la convergence des séries de Fourier. *Math. Annalen*, **61**, 251-280.
- Privaloff, J. (1919). Integrale de Cauchy. Saratoff, 1-94.
- Riesz, M. (1923). Sur la sommation des séries de Fourier. *Acta Szeged.*, **1**, 104-113.
- Young, W. H. (1914). The usual convergence of a class of trigonometrical series. *Proc. Lond. Math. Soc.*, **13**, 13-28.

BIANCHI'S CHARACTERISTIC FUNCTION IN A CONGRUENCE OF RIBAUCCOUR.

By RAM BEHARI and RATAN SHANKER MISHRA, *University of Delhi.*

(Received October 10 ; read November 25, 1949.)

The object of this paper is to express Bianchi's characteristic function in terms of infinitesimal elements of the director surface and the surface of reference in a congruence of Ribaucour. It has also been expressed in terms of the distances of focal points from the surface of reference. Some new theorems have been established with the help of these results.

1. A Congruence of Ribaucour is the congruence formed by rays through points on one surface parallel to the normals to another surface, the two surfaces corresponding with orthogonality of linear elements¹. The former surface is called the surface of reference and the latter is known as the director surface.

Let x^i and y^i be the co-ordinates of the corresponding points on the director surface and the surface of reference respectively, then we must have,

$$dx^i \cdot dy^i = 0 \quad (i, j = 1, 2, 3)$$

or
$$\left(\frac{\partial x^i}{\partial u^\alpha} \cdot \frac{\partial y^j}{\partial u^\beta} + \frac{\partial x^i}{\partial u^\beta} \cdot \frac{\partial y^j}{\partial u^\alpha} \right) \epsilon_{ij} = 0, \quad \epsilon_{ij} = \delta_j^i \quad (\alpha, \beta = 1, 2) \quad \dots \quad (1.1)$$

If $g_{\alpha\beta}$, $d_{\alpha\beta}$ are the first and second fundamental tensors for the director surface, and

$$e_{\alpha\beta} e_{\gamma\delta} = g_{\alpha\gamma} g_{\beta\delta} - g_{\alpha\delta} g_{\beta\gamma} \quad \dots \quad \dots \quad (1.2)$$

then equation (1.1) may be replaced by an equivalent equation

$$\epsilon_{ij} = \frac{\partial x^i}{\partial u^\alpha} \cdot \frac{\partial y^j}{\partial u^\beta} = \phi^e_{\alpha\beta} \quad \dots \quad \dots \quad (1.3)$$

The function ' ϕ ' is known as Bianchi's characteristic function.

If X^i are the direction cosines of a normal to the surface at x^i then we have²

$$p_\gamma \equiv X^i \cdot y^i_{,\gamma} = E^{\alpha\beta} l_{\gamma\beta} \cdot \phi_{,\alpha} \quad \dots \quad \dots \quad (1.4)$$

where $E^{\alpha\beta}$ is a tensor conjugate to $E_{\alpha\beta}$, and

$$E_{\alpha\beta} \cdot E_{\gamma\delta} = G_{\alpha\gamma} G_{\beta\delta} - G_{\alpha\delta} G_{\beta\gamma},$$

$G_{\alpha\beta}$ being the covariant components of the fundamental tensor for the spherical representation of the director surface.

The first fundamental tensor for the surface of reference is given by,³

$$a_{\alpha\beta} = g_{\alpha\beta} \phi^2 + p_\alpha p_\beta \quad \dots \quad \dots \quad (1.5)$$

If
$$\bar{e}_{\alpha\beta} \bar{e}_{\gamma\delta} = a_{\alpha\gamma} a_{\beta\delta} - a_{\alpha\delta} a_{\beta\gamma}$$

$$[\bar{e}_{\alpha\beta} e^{\alpha\beta}]^2 = \phi^4 + p_\alpha p_\beta g^{\alpha\beta} \phi^2 \quad \dots \quad \dots \quad (1.6),$$

$$= \phi^4 + p_\alpha p_\beta g_{\delta\gamma} e^{\alpha\gamma} e^{\beta\delta} \phi^2 \quad \dots \quad \dots \quad (1.7)$$

$$\begin{aligned}
 \text{or} \quad & [\bar{e}_{\alpha\beta} e^{\alpha\beta}]^2 = \phi^4 + p_\alpha p_\beta e^{\alpha\gamma} e^{\beta\delta} (a_{\delta\gamma} - p_\gamma p_\delta) \\
 \text{or} \quad & [\bar{e}_{\alpha\beta} e^{\alpha\beta}]^2 = \phi^4 + p_\alpha p_\beta e^{\alpha\gamma} e^{\beta\delta} a_{\delta\gamma} \text{ since } p_\alpha p_\beta p_\gamma p_\delta e^{\alpha\gamma} e^{\beta\delta} = 0 \\
 \text{or} \quad & [\bar{e}_{\alpha\beta} e^{\alpha\beta}]^2 = \phi^4 + (\bar{e}_{\alpha\beta} e^{\alpha\beta})^2 p_\alpha p_\beta \bar{e}^{\alpha\gamma} \bar{e}^{\beta\delta} a_{\gamma\delta} \quad \dots \quad \dots \quad \dots \quad (1.8)
 \end{aligned}$$

$$\text{But} \quad p_\alpha p_\beta \bar{e}^{\alpha\gamma} \bar{e}^{\beta\delta} a_{\gamma\delta} = \sin^2 \theta \quad \dots \quad \dots \quad \dots \quad (1.9)$$

where θ is the angle which a ray of the congruence makes with the normal to the surface of reference.

$$\text{Hence} \quad \bar{e}_{\alpha\beta} e^{\alpha\beta} \cos \theta = \phi^2$$

$$\text{or} \quad \frac{ds_1}{ds} \cos \theta = \phi^2 \quad \dots \quad \dots \quad \dots \quad (1.10)$$

where ds_1 , and ds are the areas of small elements on the surface of reference and the director surface.

Thus we see that Bianchi's characteristic function is denoted by the equation (1.10)

By Strazzeri's formula ⁴,

$$\frac{ds_1}{d\sigma} \cos \theta = \rho_1 \rho_2 \quad \dots \quad \dots \quad \dots \quad (1.11)$$

where ρ_1 and ρ_2 are the distances of the focal points from the surface of reference and $d\sigma$ is the element of area of the spherical representation of the congruence.

Dividing equation (1.10) by the equation (1.11) we get,

$$\frac{d\sigma}{ds} = \frac{\phi^2}{\rho_1 \rho_2}$$

But by the theorem of Gauss

$$\frac{d\sigma}{ds} = k,$$

the total curvature of the director surface.

$$\therefore \phi^2 = k \rho_1 \rho_2 = -k \rho^2 \text{ where } \rho_1 = -\rho_2 = -\rho \text{ (say)} \quad \dots \quad (1.12)$$

Thus *Bianchi's characteristic function can also be expressed in terms of total curvature of director surface and the distances of focal points from the surface of reference.*

In particular, if we consider Isotropic congruences, then the director surface is a unit sphere, whose total curvature is unity.

$$\therefore \phi^2 = -\rho^2$$

But ' ϕ ' can be shown to be the factor of proportionality between the corresponding coefficients of Sannia's two quadratic forms and hence is real

$$\therefore \rho \text{ is imaginary,}$$

i.e. the focal points of an Isotropic congruence are imaginary. When the focal points coincide with the middle point, i.e. when the congruence is normal, Bianchi's characteristic function vanishes and the middle surface reduces to a point.

From the formula (1.10) it follows that if ϕ vanishes, $ds_1 = 0$, i.e. the congruence consists of rays through a point.

2. The equation (1.9) gives an expression for $\sin^2 \theta$ in terms of the covariant components of the fundamental tensor for the surface of reference. We shall now establish an expression for θ in terms of the covariant components of the fundamental tensor for the director surface.

From the equations (1.7), (1.8) and (1.9) we get

$$p_\alpha p_\beta g_{\delta\gamma} e^{\alpha\gamma} e^{\beta\delta} \cdot \phi^2 = [\bar{e}_{\alpha\beta} e^{\alpha\beta}]^2 \sin^2 \theta$$

or $p_\alpha p_\beta g^{\alpha\beta} = \sin^2 \theta (\phi^2 + p_\alpha p_\beta g^{\alpha\beta})$ by virtue of (1.6)

$$\therefore \tan^2 \theta = \frac{1}{\phi^2} p_\alpha p_\beta g^{\alpha\beta} \quad \dots \quad (2.1)$$

When expanded this equation becomes

$$\tan^2 \theta = \frac{(p_2)^2 g_{11} + (p_1)^2 g_{22} - 2g_{12} p_1 p_2}{\phi^2 (g_{11} g_{22} - g_{12}^2)}$$

Another expression for $\tan \theta$ can be obtained by putting the values of p_γ from (1.4)

$$\tan^2 \theta = \frac{1}{\phi^2} [E^{\gamma\delta} E^{\rho\nu} \phi_{,\gamma} \phi_{,\rho} d_{\alpha\delta} d_{\beta\nu} g^{\alpha\beta}]$$

But $G_{\alpha\beta} = d_{\alpha\delta} d_{\beta\nu} g^{\delta\nu} \quad \dots \quad (2.2)$

\therefore The equation (2.2) becomes

$$\tan^2 \theta = \frac{1}{\phi^2} E^{\gamma\delta} E^{\rho\nu} \phi_{,\gamma} \phi_{,\rho} G_{\delta\nu}$$

or $\tan^2 \theta = \frac{1}{\phi^2} \phi_{,\gamma} \phi_{,\rho} G^{\gamma\rho}$

When expanded this equation becomes

$$\tan^2 \theta = \frac{\left(\frac{\partial \phi}{\partial u^2}\right)^2 G_{11} + \left(\frac{\partial \phi}{\partial u^1}\right)^2 G_{22} - 2\frac{\partial \phi}{\partial u^1} \cdot \frac{\partial \phi}{\partial u^2} \cdot G_{12}}{\phi^2 (G_{11} G_{22} - G_{12}^2)}$$

If Y^i are the direction cosines of the normal to the surface of reference

then $Y^i = z^i e_{\alpha\beta} \bar{e}^{\alpha\beta} \quad \dots \quad (3.1)$

where z^i are the co-ordinates of the corresponding points on the surface S_0 associated to the director surface.

From equation (1.10) this equation becomes

$$Y^i = z^i \cos \theta. \quad \dots \quad (3.2)$$

If $\theta = 0$ the congruence consists of normals to the surface of reference,

$$Y^i = z^i.$$

Hence in a congruence of Ribaucour, formed by normals to the surface of reference, the surface associated to the director surface is a sphere. Conversely, if the surface S_0 is a sphere, then from (3.2).

$$Y^i = z^i \cos \theta$$

$$Y^i Y^i = z^i z^i \cos^2 \theta$$

$$\text{or } \cos \theta = 1 \text{ or } \theta = 0.$$

Hence if the surface associated to the director surface of a congruence of Ribaucour is a sphere, the congruence consists of rays normal to the surface of reference.

4. From (1.5), the null lines on the surface of reference are given by

$$a_{\alpha\beta} du^\alpha du^\beta \equiv \phi^2 g_{\alpha\beta} du^\alpha du^\beta + p_\alpha p_\beta du^\alpha du^\beta = 0. \quad \dots \quad (4.1)$$

Thus the null lines on the surface of reference correspond to the null lines on the director surface if

$$p_\alpha p_\beta du^\alpha du^\beta = 0$$

or

$$(p_\alpha du^\alpha)^2 = 0,$$

which is true if the congruence is formed by normals to the surface of reference. Hence if a congruence of Ribaucour is formed by normals to the surface of reference, the null lines on the surface of reference and the director surface correspond.

From the equation (1.3) the relation between the director surface and the surface of reference is reciprocal. Therefore the equation (1.3) can also be written as

$$\epsilon_{ij} \frac{\partial x^i}{\partial u^\alpha} \cdot \frac{\partial y^j}{\partial u^\beta} = \phi_1 \bar{e}_{\alpha\beta} \quad \dots \quad (4.2)$$

where ϕ_1 also is 'Bianchi's characteristic function,' but with respect to \bar{e}_{12} of the surface of reference.

From the equations (1.3) and (4.1)

$$\phi_1 \bar{e}_{\alpha\beta} = \phi e_{\alpha\beta}$$

or

$$\frac{\bar{e}_{\alpha\beta}}{e_{\alpha\beta}} = \frac{\phi}{\phi_1} \quad \text{or} \quad \frac{ds_1}{ds} = \frac{\phi}{\phi_1}.$$

Using equation (1.10)

$$\phi \phi_1 = \cos \theta. \quad \dots \quad (4.3)$$

i.e. the cosine of the angle between a ray of a congruence of Ribaucour and the normal to the surface of reference at the point where the ray cuts it is the product of Bianchi's two characteristic functions.

REFERENCES.

1. Eisenhart: Differential Geometry of curves and surfaces, p. 420.
2. Eisenhart: loc. cit., p. 375.
3. Eisenhart, loc. cit., p. 390, ex. 4.
4. Strazzeri, sulle Congruenze di retti, Rendiconti del circolo Matematico di Palermo, 1927, p. 138.
5. Eisenhart, loc. cit., p. 382.

THE EMBRYO SAC OF *FRITILLARIA LILIACEA*.

By J. S. AGRAWAL, *Department of Botany, University of Delhi.*

(Communicated by Prof. P. Maheshwari, F.N.I.)

(Received November 18, 1949; read January 2, 1950.)

INTRODUCTION.

Fritillaria liliacea belongs to the family Liliaceae, tribe Lilioideae. Three species of the genus, *F. persica* (Bambacioni, 1928a), *F. imperialis* (Lenoir, 1934) and *F. pudica* (Sax, 1916; Eunos, 1950), have so far been studied. It was in *F. persica* that a 1+3 arrangement of the megaspore nuclei and the so-called 'Carano-Bambacioni Effect' (see Maheshwari, 1946) were first discovered by Bambacioni (1928a). After the primary four-nucleate stage, there is a secondary four-nucleate stage in which the two micropylar nuclei are haploid and the two chalazal nuclei are triploid. In the next stage the basal nucleus remains undivided resulting in a seven-nucleate embryo sac with only two antipodal cells.

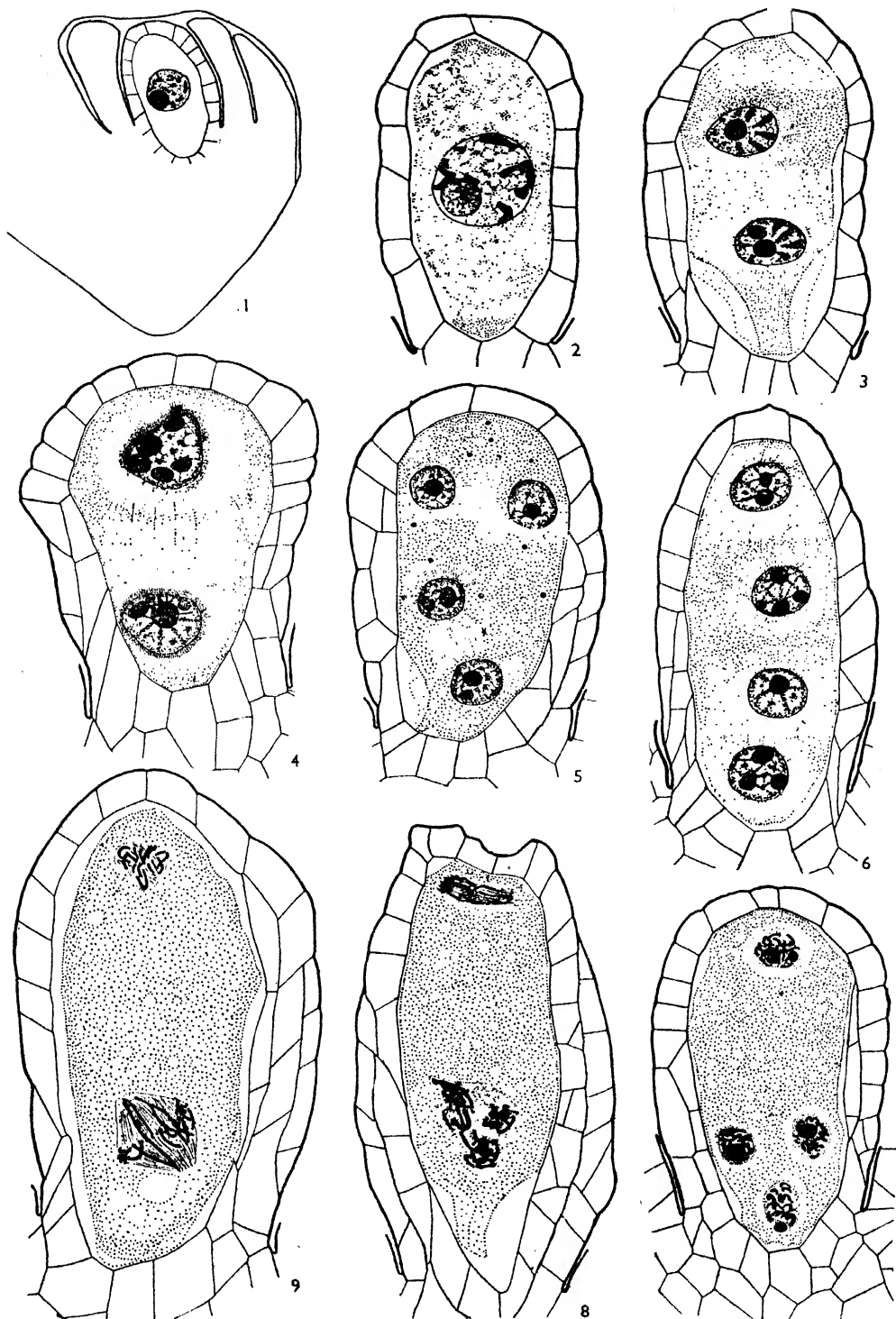
MATERIAL AND METHODS.

The material used for this investigation was obtained from Mrs. M. S. Cave (University of California) by Prof. P. Maheshwari and very kindly passed on to me for study. Sections were cut 15 μ thick and stained in Heidenhain's iron-alum haematoxylin.

OBSERVATIONS.

The trilocular ovary has a large number of anatropous, bitegmie ovules arranged in two rows on an axile placenta. The integuments are well advanced even at the megaspore mother cell stage (Fig. 1). The outer integument is three- to four- layered. The inner is two- to three- layered but later it becomes four cells thick at the micropylar end.

A single hypodermal archesporial cell differentiates in the nucellus. This functions directly as the megaspore mother cell without cutting off any wall cell. Its cytoplasm is finely granular, dense, and devoid of any conspicuous vacuoles (Fig. 2). Following the first reduction division one daughter nucleus migrates to the micropylar end and the other to the chalazal end without any wall formation between them (Figs. 3, 4). Each nucleus has several prominent nucleoli. The second reduction division produces the four free megaspore nuclei arranged diagonally (Fig. 5) or in a linear row (Fig. 6). In slightly older ovules only one megaspore nucleus is seen at the micropylar end and three at the chalazal end thus producing a 1+3 arrangement (Fig. 7). All the four megaspore nuclei divide simultaneously (Fig. 8), but the spindles of three chalazal nuclei fuse to form a large common spindle (Fig. 9) which may be situated diagonally (Fig. 10) or at right angles to the long axis of the embryo sac. At the end of the division there is seen a secondary four-nucleate stage with two small haploid nuclei at the micropylar end and two large triploid nuclei at the chalazal end (Figs. 10, 11). Earlier investigators (Sargant, 1896; Mottier, 1897) assumed the larger size of the two chalazal nuclei as probably due to their own growth because this condition was found only in the larger embryo sacs.



TEXT-FIGS. 1-9.—(See p. 89 for Explanation).

The two chalazal nuclei elongate and become slightly flattened, while remnants of the spindle fibres can be identified between them for a long time. Vacuolation begins in the embryo sac at about this stage (Figs. 10, 11). In *Lilium philippinense* (Santos, 1937), the condition is similar, but in most other plants showing the *Fritillaria* type of development vacuolation seems to begin much earlier. As examples may be cited *Tulipa* (Bellows and Bamford, 1941), *Tamarix ericoides* (Sharma, 1939), *Piper longum* (Joshi, 1944), *Clintonia* (Walker, 1944; Smith, 1943), *Erythronium dens canis* (Hruby, 1934) and *Erythronium tuolumnense* (Cave, 1942). Joshi's (1940) figures of *Gagea fascicularis*, showing vacuolation only at the mature embryo sac stage, seem to be rather unusual in this respect. In *G. graminifolia*, studied by Romanov (1936), vacuolation is clearly seen at the time of the third division in the embryo sac prior to the secondary four-nucleate stage.

At the time of the fourth and the last nuclear division a vacuole appears in the upper part which gradually enlarges and occupies the central part of the embryo sac separating the micropylar and the chalazal groups of nuclei. Only the two micropylar nuclei and the upper triploid nucleus take part in this division (Fig. 12) producing a 7-nucleate embryo sac with four nuclei at the micropylar end and three at the chalazal. The basal chalazal nucleus shows signs of early degeneration.

The four micropylar nuclei give rise to the egg apparatus and the upper polar nucleus. Of the three chalazal nuclei, the uppermost, which is the largest, functions as the lower polar nucleus and the remaining two as the antipodal cells (Fig. 13). The three cells of the egg apparatus are more or less symmetrically arranged. The largest of the three functions as the egg. Neither the synergids nor the egg showed any prominent vacuolation.

ABNORMALITIES.

A few abnormal embryo sacs were noticed which are briefly described below.

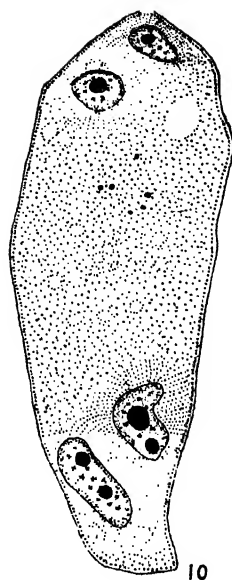
In one case all the four megaspore nuclei of the primary four-nucleate stage showed signs of early degeneration while in some others only one, two or three nuclei were degenerating.

One embryo sac, of a smaller size than the others, showed all the four megaspore nuclei in division (Fig. 14) indicating an *Adoxa* type of development. This is very important because it indicates that there is no fixed mode of development in *Fritillaria*. Such a condition has also been recorded in *Erythronium* (see Maheshwari, 1946) and some other genera with tetrasporic embryo sacs.

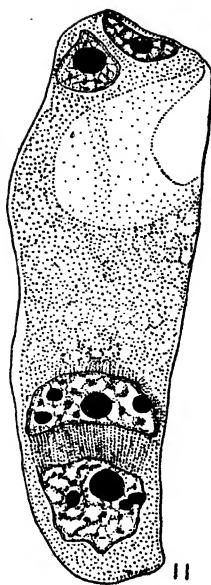
Sometimes the egg apparatus may consist of only a single synergid and the egg, the resulting embryo sacs being 6-nucleate (Figs. 15, 16). From Sax's (1916) Figs. 2 and 3 of *Fritillaria pudica* and Joshi's (1944) Fig. 23 of *Piper longum* also it appears that sometimes only one synergid may be formed instead of two. Although Sax mentions that 'in practically all cases one of the synergids is destroyed by the entering pollen tube', yet there seems to be no trace of the degenerating synergid in his Figs. 2 and 3. It is possible that at the time of the fourth nuclear division one of the micropylar nuclei also fails to divide in addition to the basal chalazal nucleus.

EXPLANATION OF FIGURES (on p. 88).

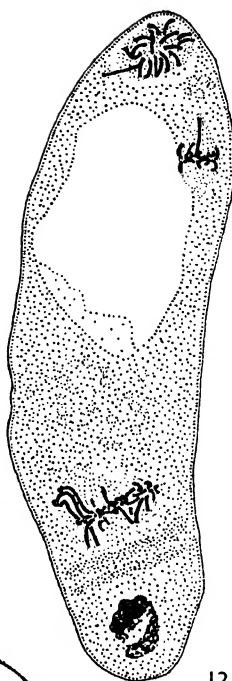
Figs. 1-9. Early stages in the development of the embryo sac. Fig. 1. L.s. ovule at megaspore mother cell stage, $\times 206$. Fig. 2. Megaspore mother cell in meiotic prophase, $\times 432$. Fig. 3. Same, late telophase, $\times 432$. Fig. 4. Two nuclei arising after the first reduction division; remnants of the spindle fibres are still visible, $\times 432$. Fig. 5. Late telophase of the second reduction division, $\times 432$. Fig. 6. Four free megaspore nuclei arranged in a linear row, $\times 432$. Fig. 7. Typical 1+3 arrangement of the megaspore nuclei, $\times 432$. Fig. 8. Third nuclear division showing fusion of the three chalazal spindles, $\times 432$. Fig. 9. Same, more advanced stage, $\times 432$.



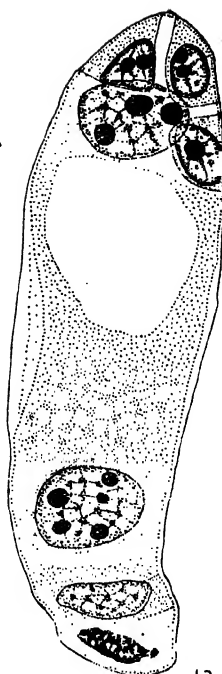
10



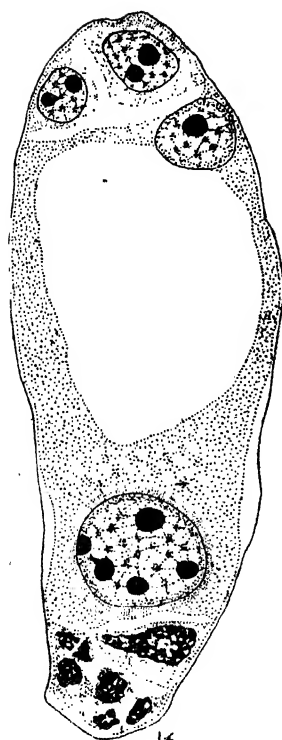
11



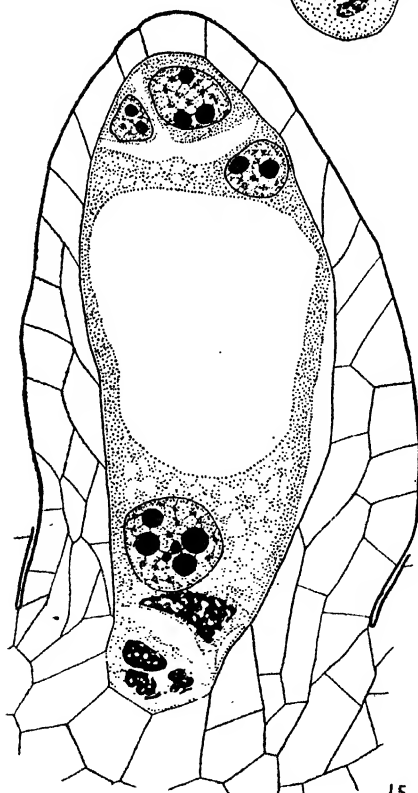
12



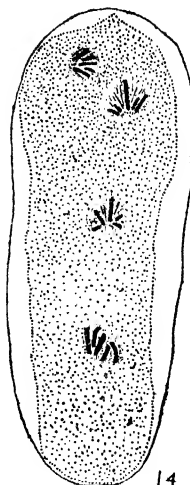
13



16



15



14

TEXT-FIGS. 10-16.—(See p. 91 for Explanation).

Some embryo sacs were observed with the synergids or the entire egg apparatus in process of degeneration before the entry of the pollen tube.

Frequently, the nucleus of the basal antipodal cell fragments (Fig. 15) into as many as 6 or 7 nuclei resulting in the formation of supernumerary antipodal cells (Fig. 16). Such a condition has not been reported previously in *Fritillaria* but was seen in several embryo sacs of *F. liliacea*. Early degeneration sets in, however, and the antipodal cells appear as structureless darkly staining masses surrounded with shrunken cytoplasm.

SUMMARY.

1. The trilocular ovary has numerous anatropous, bitegmic ovules in two longitudinal rows on an axile placenta.
2. The hypodermal archesporial cell functions directly as the megaspore mother cell which undergoes the usual reduction divisions and produces the primary four-nucleate stage.
3. Following a 1+3 stage all the megaspore nuclei divide simultaneously but the three chalazal spindles unite to form a large common spindle resulting in a secondary four-nucleate embryo sac.
4. One more division occurs, the basal triploid nucleus usually remaining undivided.
5. The mature embryo sac is 7-nucleate and consists of four haploid cells (the egg, two synergids and the upper polar) and three triploid cells (the two antipodal cells and the lower polar nucleus). There is no sharp distinction between the synergids and the egg. All the nuclei of the embryo sac show several nucleoli in each.
6. In one case all the four megaspore nuclei were seen dividing independently indicating an Adoxa type of development. Sometimes only one synergid was seen in place of two. Frequently, the basal antipodal cell fragments and gives rise to supernumerary antipodal cells.

ACKNOWLEDGMENTS.

It is a great pleasure to acknowledge my indebtedness to Dr. B. M. Johri under whose guidance the work was carried out. I am indebted to Prof. P. Maheshwari for providing the material and going through the manuscript and to Dr. B. Singh of the B.R. College, Agra, for his advice and encouragement.

REFERENCES.

- Bambacioni, V. (1928a). Ricerche sulla ecologia e sulla embriologia di *Fritillaria persica* L. *Ann. Bot. (Roma)*, **18**, 7-37.
- (1928b). Contributo alla embriologia di *Lilium candidum* L. *R. C. Accad. Lincei*, **8**, 612-18.
- Bellows, J. M. (Jr.) and Bamford, R. (1941). Megagametophyte development in a triploid tulip. *Bot. Gaz.*, **102**, 699-711.
- Cave, M. S. (1942). Development of the female gametophyte in *Erythronium helenae* and *E. tuolumnense*. *Madrono*, **6**, 177-81.
- Cooper, D. C. (1934). Development of the embryo sac of *Lilium henryi*. *Proc. Nat. Acad. Sci. U.S.A.*, **20**, 163-66.
- Eunus, A. M. (1950). Development of the embryo sac and fertilization in *Fritillaria pudica*. (In press.)
- Hruby, C. H. (1934). A contribution to the cytology and embryology of *Erythronium dens-canis* L. *Bull. Int. Acad. Sci. Bohême*, 1934, pp. 1-9.
- Joshi, A. C. (1940). Development of the embryo sac in *Gagea fascicularis* Salisb. *Bull. Torrey Bot. Cl.*, **67**, 155-158.
- (1944). Structure and development of the ovule and embryo sac of *Piper longum* L. *Proc. Nat. Inst. Sci. India*, **10**, 105-112.

EXPLANATION OF FIGURES (on p. 90).

FIGS. 10-16. Later stages in the development of the embryo sac. FIGS. 10-11. Secondary four-nucleate stages, $\times 432$. FIG. 12. Fourth nuclear division in which the lowest chalazal nucleus has failed to divide, $\times 432$. FIG. 13. Mature seven-nucleate embryo sac, $\times 432$. FIG. 14. An abnormal case in which all the four free megaspore nuclei are dividing independently, $\times 432$. FIG. 15. Embryo sac showing a single synergid, egg, two polar nuclei and two antipodal cells of which the basal shows three nuclei, probably formed by a fragmentation of the original nucleus, $\times 432$. FIG. 16. Same, the basal cell has divided into six fragments, $\times 432$.

- Lenoir, M. (1934). Les divisions II et III dans le sac embryonnaire du *Fritillaria imperialis* L. *C. R. Soc. Biol. Paris*, **116**, 442-443.
- Maheshwari, P. (1946). The *Fritillaria* type of embryo sac: A critical review. *Jour. Ind. Bot. Soc.: M. O. P. Iyengar Comm. Vol.*, 101-119.
- Mottier, D. M. (1897). Über das Verhalten der Kerne bei der Entwicklung des Embryosackes und die Vorgänge bei der Befruchtung. *Jahrb. f. wiss. Bot.*, **31**, 125-58.
- Romanov, I. D. (1936). Die Embryosackentwicklung in der Gattung *Gagea* Salisb. *Planta*, **25**, 438-59.
- Santos, J. K. (1937). Macrosporogenesis in *Lilium philippinense*. *Cytologia, Fujii Jubl. Vol.*, 822-35.
- Sargaut, E. (1896). Direct nuclear division in the embryo sac of *Lilium Martagon*. *Ann. Bot. (Lond.)*, **10**, 107-108.
- Sax, K. (1916). Fertilisation in *Fritillaria pudica*. *Bull. Torrey Bot. Cl.*, **43**, 505-22.
- Sharma, Y. M. L. (1939). Gametogenesis and embryogeny in *Tamarix ericoides* Rottl. *Ann. Bot., N.S.*, **3**, 861-70.
- Smith, F. H. (1943). Megagametophyte of *Clintonia*. *Bot. Gaz.*, **105**, 263-67.
- Walker, R. L. (1944). Chromosome number, megasporogenesis and development of embryo sac of *Clintonia*. *Bull. Torrey Bot. Cl.*, **71**, 529-35.

STUDIES ON THE EMBRYOLOGY OF MICROCHIROPTERA, PART VI.

STRUCTURE OF THE PLACENTA IN THE INDIAN VAMPIRE BAT, *Lyroderma lyra lyra* (GEOFFROY)—(MEGADERMATIDAE).

By A. GOPALAKRISHNA, *Department of Zoology, College of Science, Nagpur.*

(Communicated by Prof. M. A. Moghe, F.N.I.)

(Received October 10; read November 25, 1949.)

I. INTRODUCTION.

Very little is known of the life-history, development and placentation of the family Megadermatidae. According to Blanford (1881) *Megaderma* (*Lyroderma*) *lyra lyra* is the only species commonly found in India. The only bit of information from that source is that 'Hodgson has observed that in this species males greatly exceed the females in numbers'.....'Anderson found the young adhering to the abdominal teats and moving about from them to the pectoral mammae'.....'Hodgson found a single young in many pregnant females examined by him at the end of February.' This information is obviously very insufficient.

In this paper I propose to record a few observations on the reproductive system and to describe the foetal membranes and the structure of the placenta. The material at my disposal is not sufficient and I cannot describe the sex-cycle or the early development of this bat.

II. MATERIAL AND METHODS.

The bats were collected from old houses and cowsheds in two villages—Lakhani and Shipewada—in Bhandara district, Central Provinces, India. The specimens were brought to the laboratory in cages. The reproductive structures and the mammary glands of the females were fixed in Bouin's fixative, the pregnant uteri were slit open or punctured to allow the penetration of the fixative. After dehydration they were sectioned at a thickness of 10μ and stained with Ehrlich's haematoxylin and counterstained with eosin. In cases of the males the reproductive organs, kidneys and the suprarenals were fixed. In addition to Bouin's fixative, which was used as a routine fixative, Carnoy's fluid, Sanfelice's formula and formalin were also employed to fix the testes.

III. OBSERVATIONS AND CONCLUSIONS.

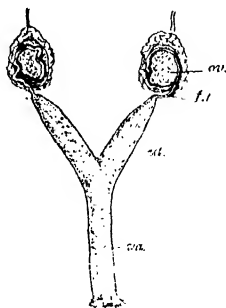
The following table gives the data of collections (specimens were collected during 1947 and 1948):—

				Males.	Females.
February	..	..	..	7	7
March	..	..	..	4	6
July	..	..	..	10	5
August	..	..	..	5	11
October	..	..	..	2	13
November	..	..	..	0	1
				—	—
			TOTAL ..	28	43

(a) *The female reproductive structures :—*

The ovaries are flattened structures, ellipsoidal in shape and having a diameter of 0.4 mm. in section. The ovary is enclosed inside a complete ovarian capsule, hence the corpus luteum does not project beyond the surface of the ovary.

The Fallopian tube arises from the lateral side of the ovarian capsule, has a circuitous course and emerges as a fine tube from the caudal aspect of the ovarian capsule. The uterine cornua are symmetrically placed in the form of the two limbs of a 'V' across the median line. In the non-pregnant females the two horns are equally well developed, and each has a length of 0.8 cm. Pregnancy occurs only in one horn. The vagina has a length of 1.2 cm. (Text fig. 1.)



TEXT-FIGURE 1.

The female genitalia in *Lyroderma lyra lyra* (Geoffroy). Ov.: ovary; f.t.: fallopian tube. Ut.: uterus; vg.: vagina.

There are a pair of pectoral mammae each with a single teat. There are also a pair of pubic teats without any pubic mammary glands. The pubic nipples are well developed in the case of the parous forms and measures in length 1.3 cm. while in the case of the virgin females the pubic nipples are small and are not more than 0.6 cm. in length. The pubic nipples are covered with fine fur. It has been suggested by Harrison Matthews (1937) that they increase greatly in size during the first pregnancy and lactation, and having once developed they do not return to their original condition. He, therefore, suggests that the large size of the pubic nipples is a sure indication of the sexual maturity of the female bats.

(b) *Number of embryos in litter :—*

The physiological asymmetry of the genitalia of the Chiroptera is a well-established fact. (Wood Jones, 1917; Harrison Matthews, 1937 and 42; Wimsatt, 1945). In most species, which have been studied, only one young is brought forth in each litter and pregnancy usually occurs in the right horn. (Duval, 1895; Wood Jones 1917; Guthrie, 1933; Baker and Bird, 1936; Harrison Matthews, 1937; Wimsatt, 1945). In extreme cases like *Rhinolophus hipposideros* (Harrison Matthews, 1937) the left horn does not even produce mature ova, indicating the final stage in the functional degeneration of the left part of the genitalia. Only in the case of the members belonging to the family Phyllostomatidae there is a simplex uterus as in *Glossophaga soricina* (Hamlett, 1934 and 1935) and *Artibeus jamaicensis parvipes* (Wislocki and Fawcett, 1941). Perfect bilateral symmetry with both the horns bearing embryos is found in some Vespertilionid bats such as *Vesperugo leisleri* (Ramaswami, 1933), *Scotophilus wroughtoni* and *S. temminki* (Gopalakrishna, 1947). In *Lyroderma lyra lyra* there is a single young in each litter, either in the

left horn or in the right horn. It was observed that in every pregnant female the ovary on the same side as the side of pregnancy had the corpus luteum. Furthermore the ovary on the other side showed no signs of degeneration.

There is another fact of considerable interest which I desire to record. Of the 13 females collected during February and March (pregnancies were observed only during these two months) 10 were pregnant. Of the 10 pregnant females 4 bore pregnancy in the right horn and 6 in the left horn of the uterus. These specimens which showed pregnancy in right horn had small pubic teats while those that had pregnancy in the left horn had large pubic teats. The small number of my collections does not encourage me to offer any opinion at present on the statement made by Harrison Matthews (1937) in explanation of this fact.

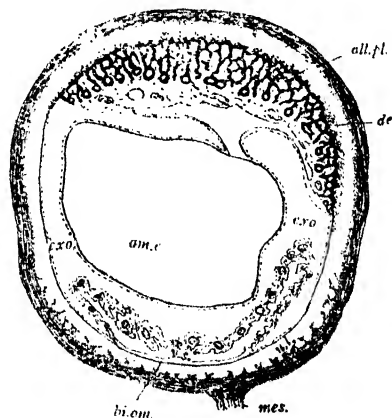
IV. PLACENTATION.

(a) Arrangement of foetal membranes:—

The stage of development, on which this account is based, is an advanced stage of development collected in February. The foetus shows the beginnings of the ossification of the long bones, and the foetal erythrocytes are enucleate. The foetal membranes have attained their definitive disposition and final structural differentiation. The uterus has a diameter of 2.2 cm. in the transverse axis and 2.7 cm. in the tubo-cervical axis.

The general topography of the foetal membranes is indicated in text-fig. 2. There is a discoidal chorio-allantoic placenta on the antimesometrial side of the uterus. The allantoic diverticulum is situated slightly to one side of the median line. The allantois carrying foetal vessels spreads fanwise at the base of the placenta.

The yolk-sac occurs in the section as a crescentic space on the mesometrial side. The vascular splanchnopleure is separated from the bilaminar ophalopleure by a slit-like space. The bilaminar omphalopleure does not come into contact with the uterine wall, hence a small part of the uterine lumen persists on the mesometrial side of the uterus. The connection between the foetal gut and the yolk-sac cavity is lost as the yolk stalk has become solid.



TEXT-FIGURE 2.

A diagrammatic transverse section of the gestation sac to show the arrangement of the foetal membranes in *Lyroderma lyra lyra* (Geoffroy). *all. pl.*: allantoic placenta; *am. c.*: amniotic cavity; *bi. on.*: bilaminar omphalopleure; *de.*: decidua; *exo.*: exocoelom; *mes.*: mesometrium; *u.l.*: uterine lumen; *y.sc.*: yolk-sac.

The general disposition of the foetal membranes in *Lyroderma lyra lyra* resembles that of most of the insectivorous bats so far studied. A decidua capsularis, as has been described in some of the Phyllostomatid bats (Hamlett, 1934 and 1935; Wislocki and Fawcett, 1941), is absent from *Lyroderma lyra lyra*.

(b) *Finer structure of the Placenta*.—

The microscopic structure of the allantoic placenta resembles that of most of the species of microchiroptera so far known, and is typically labyrinthine and haemochorial. The placenta is made up of a system of hollow syncytiotrophoblastic cords containing maternal blood which occurs in the core of the placental cords. The cords form a plexiform labyrinth and the spaces between the cords are occupied by the allantoic mesenchyme and foetal blood vessels. At the base of the placental disc (i.e. on the foetal surface) large lacunae containing maternal blood and surrounded by syncytiotrophoblast can be seen (Pl. VI, Fig. 1).

The trophoblastic cords are zigzag and traversed by a hollow core containing maternal blood, and are lined on the interior by a row of darkly staining nuclei, spherical in shape and belonging to the syncytiotrophoblast. The cords are clear and distinct towards the base of the placenta, while towards the periphery, due to their intense interjunction, they appear to be in the form of a network. The trophoblastic cords have a uniform thickness. In a cross-section of a cord, or under higher magnifications, the histological details of the cords can be clearly made out (Pl. VI, Fig. 2). The cytoplasm is disposed mostly towards the periphery and the central space is lined by a distinct row of spherical nuclei. These nuclei appear to be in direct contact with the maternal blood; in other words, they appear to form the innermost layer of the cord, but under the oil immersion objective a thin layer of cytoplasm can be clearly made out over the layer of these nuclei. Outside this layer of nuclei there is a larger area of hyaline cytoplasm with very few nuclei scattered here and there. These nuclei are flattened and lightly staining.

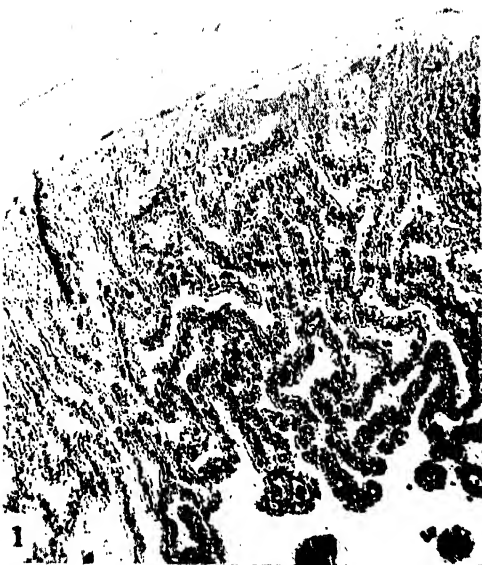
The allantoic mesenchyme and the foetal blood vessels enter the placental region from the base. They occur in between the trophoblastic cords in the meshes of the network, and extend almost about three-quarters of the thickness of the placenta.

The junctional zone between the placenta and the decidua is very clear because in this region the trophoblast forms a continuous syncytial covering to the placenta. This syncytial shell is pierced here and there by the maternal vessels which enter the placenta from the uterine side.

The zone of separation of the parturient is clearly marked out at this stage. The decidua covering round the placenta occurs as a thin layer of loose connective tissue with plenty of areoli. The space which occurs between the decidua and the uterine wall is, probably, an artefact due to shrinkage.

The maternal vessels enter the placental disc from the antimesometrial side. Up to the point where they penetrate the placenta, i.e. up to the margin of the syncytiotrophoblastic shell, the maternal vessels maintain the endothelial lining. But after the vessels enter the placental labyrinth the endothelial lining is lost, and the vessels continue down towards the base of the placenta forming the core to the trophoblastic cords. Thus the maternal vascularization of the placenta is very simple—each capillary continuing as the hollow core of the trophoblastic cord up to the base of the placenta. Some of these tubes can be seen as enlarged spaces at the base of the placenta, each space surrounded by the syncytiotrophoblast. The endothelial lining of the maternal capillaries is lost as soon as they enter the placental zone.

Thus in the placenta the foetal blood is separated from the maternal blood by (a) the foetal endothelium, (b) the allantoic mesenchyme, and (c) the trophoblast.



0.5 mm

FIG. 1.



0.2 mm

FIG. 2.

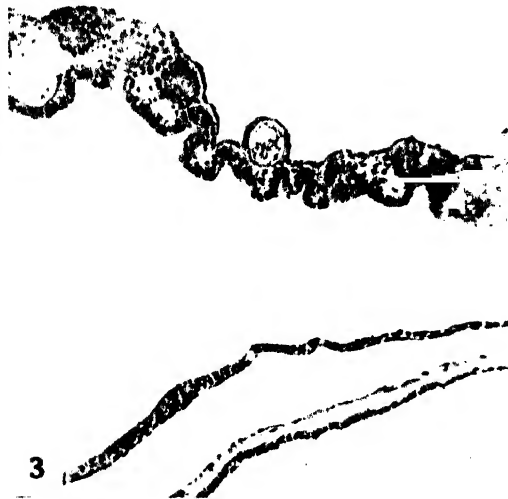


FIG. 3.

(For explanation of Plate, see page 98.)

All these structures are foetal in origin, and hence it conforms to the haemochorial type of relationship.

(c) *The Yolk-sac:*

The yolk-sac is large and occurs as a semicircular space on the mesometrial side, and extends to the lateral side to a slight extent. The splanchnopleure is supplied by vitelline vessels and the foetal erythrocytes are enucleate. At this stage the vascular splanchnopleure has no placental significance because it does not have any point of contact with the uterine tissue. (Pl. VI, Fig. 3.) On the mesometrial side the bilaminar omphalopleure still persists. There is no decidua capsularis.

V. SUMMARY.

1. The physiological asymmetry of the female genitalia in the case of *Lyroderma lyra lyra* is well recognized, because only one horn of the uterus becomes pregnant. It may be the right or the left. A single young is born in each litter.

2. Foetal membranes: ALLANTOIC PLACENTA.—*Disposition*: Antimesometrial. *Shape*: Discoidal. *Type*: Labyrinthine. *Finer morphology*: Haemochorial. **YOLK-SAC**.—Large. The vascular splanchnopleure is extensive. The bilaminar omphalopleure persists. **DECIDUA**.—A thin layer of decidua is shed at birth. There is no decidua capsularis.

ACKNOWLEDGEMENT.

I am very grateful to Prof. M. A. Moghe, Head of the Department of Zoology, College of Science, Nagpur, for his very valuable guidance and encouragement throughout this work. My thanks are also due to Mr. R. V. Ektatey, Zamindar of Lakhani, for his keen interest in collecting the bats and sending them to my laboratory.

REFERENCES.

- Baker, J. R. and T. F. Bird (1936). Seasons in a tropical rain forest (New Hebrides), Part IV. Insectivorous bats (Vespertilionidae and Rhinolophidae). *Journ. Linn. Soc. Lond. (Zool.)*, **40**, 143–161.
- Blanford, W. T. (1881). *Fauna of British India—Mammalia*. Vol. II.
- Duval, M. (1895). Étude sur l'embryologie des chiroptères. *Jour. de Anat. et. Phy. Paris*, **31**, 93–160.
- Gopalakrishna, A. (1947). Studies on the embryology of Microchiroptera, Part I. Reproduction and breeding seasons in the South Indian Vespertilionid Bat, *Scotophilus urographon* (Thomas). *Proc. Ind. Acad. Sci. (B)*, **26**, 219–232.
- Guthrie, M. J. (1933). The reproductive cycles in some cave bats. *Jour. Mammal.*, **14**, 199–215.
- Hamlett, G. W. D. (1934). Implantation und Embryonalhüllen bei zwei sudamerikanischen Fledermäusen. *Anat. Anz.*, **79**, 146–149.
- (1935). Notes on the embryology of a phyllostomid bat. *Amer. Jour. Anat.*, **56**, 327–353.
- Harrison Matthews, L. (1937). The female sexual cycle in the British horse-shoe bats. *Trans. Zool. Soc. Lond.*, **33**, 224–266.
- (1942). Notes on the genitalia and reproduction of some African bats. *Proc. Zool. Soc. Lond.*, ser. B., **III**, 289–346.
- Ramaswami, L. S. (1933). Some stages of the placentation in *Vesperugo leisleri* (Kuhl). *Half-Yearly Jour. Mys. Univ.*, **7**, 1–41.
- Wimsatt, W. A. (1945). Notes on the breeding, behaviour, pregnancy, and parturition in some vespertilionid bats of the Eastern United States. *Jour. Mammal.*, **26**, 23–33.
- Wislocki, G. B. and D. W. Fawcett (1941). The placentation of the Jamaican bat (*Artibeus jamaicensis parvipes*). *Anat. Rec.*, **81**, 307–312.
- Wood Jones, F. (1917). Genitalia of Chiroptera. *Jour. Anat.*, **51**, 36–117.

EXPLANATIONS OF PLATE VI.

(All figures are photomicrographs.)

FIG. 1. Part of the allantoic placenta. The syncytiotrophoblastic cords are distinct only towards the foetal surface, while on the uterine surface the cords get intermingled. The spaces between the cords contain the allantoic mesenchyme and foetal vessels. A few foetal capillaries are seen at the base of the placenta. Note a thin layer a decidua covering the placenta.

FIG. 2. Magnified picture of a part of the allantoic placenta to show the details of the syncytiotrophoblastic cords. The cords are clearly seen to be tubular and the lumen of the tube contains maternal blood. The nuclei of the syncytiotrophoblast form a continuous lining to the lumen of the cords.

FIG. 3. A part of the yolk-sac wall enlarged. The figure includes the persistent bilaminar omphalopleure and also the vascular splanchnopleure, which has invaginated over the bilaminar omphalopleure. The yolk-sac cavity occurs between these two layers. (Magnification same as plate figure 2).

ON NUMBERS WHICH CAN BE EXPRESSED BY A GIVEN FORM.

By KULENDRA N. MAJUMDAR.

(Communicated by Prof. Ram Behari, Sc.D., F.N.I.)

(Received August 30 ; read October 7, 1949.)

In their paper 'On numbers which can be expressed as a sum of two squares' Bambah and Chowla (1947) have established the following theorem (first obtained by Dr. Vijayaraghavan) :—

Let ϵ denote an arbitrary positive number. Then there exists between x and $x + 2\sqrt{2+\epsilon} x^{1/4}$ an integer which can be expressed as a sum of two squares (of integers) for all $x > x_0(\epsilon)$.

Using more straightforward arguments one can, however, establish the following :—

THEOREM 1. Between x and $x + 2\sqrt{2} x^{1/4} + 1$ there exists at least one integer which can be expressed as a sum of two squares of integers for all $x \geq 0$.

The proof of this theorem will be clear from the sequel.

The object of the present paper is to study a similar but more general problem. More precisely, we try to find a function $f(x)$ such that between x and $x + f(x)$ there lies at least one number expressible by means of a given function with its arguments taking integral values. In this paper we take this function to be

$$\alpha_1 x_1^{\theta_1} + \alpha_2 x_2^{\theta_2} + \dots + \alpha_n x_n^{\theta_n} \text{ where } \theta_i > 1, \alpha_i > 0.$$

Then we show that

$$f(x) = O(x^{(1-1/\theta_1)(1-1/\theta_2)\dots(1-1/\theta_n)}).$$

Bambah and Chowla's reasonings, it appears, cannot be generalized easily to obtain this result.

THEOREM 2. Given any arbitrary form

$$\alpha_1 x_1^{\theta_1} + \alpha_2 x_2^{\theta_2} + \dots + \alpha_n x_n^{\theta_n}$$

with $\alpha_i > 0, \theta_i > 1$, then for any positive ϵ there exists between x and

$$x + Cx^{(1-1/\theta_1)(1-1/\theta_2)\dots(1-1/\theta_n)}$$

where $C = C_0(1+\epsilon), C_0 = C_0(\alpha_1, \alpha_2, \dots, \alpha_n, \theta_1, \theta_2, \dots, \theta_n), x > x_0(\epsilon)$,

at least one number which can be expressed by means of the given form with its x 's taking integral values.

Given x , choose the unique integer x_1 defined by

$$\left(\frac{x}{\alpha_1}\right)^{1/\theta_1} = x_1 + \epsilon_1, \quad 0 < \epsilon_1 < 1.$$

In other words we take x_1 to be the greatest integer contained in

$$\left(\frac{x}{\alpha_1}\right)^{1/\theta_1}.$$

Then

$$\alpha_1 x_1^{\theta_1} = \alpha_1 \left\{ \left(\frac{x}{\alpha_1}\right)^{1/\theta_1} - \epsilon_1 \right\}^{\theta_1} = x - \rho_1 x^{(1-1/\theta_1)} \dots \dots \dots (1)$$

where $0 < \rho_1(x) < \theta_1 \alpha_1^{1/\theta_1}$ provided $x > \text{some } x'$.

Of course $\overline{L}\rho_1(x) = \theta_1 \alpha_1^{1/\theta_1}$.

Next take the unique integer x_2 given by

$$\left\{ \frac{\rho_1 x^{(1-1/\theta_1)}}{\alpha_2} \right\}^{1/\theta_2} = x_2 + \epsilon_2, \quad 0 < \epsilon_2 < 1.$$

Then $\alpha_2 x_2^{\theta_2} = \rho_1 x^{(1-1/\theta_1)} - \rho_2 x^{(1-1/\theta_1)(1-1/\theta_2)} \dots \dots \dots (2)$

where $0 < \rho_2(x) < \theta_2 \theta_1^{(1-1/\theta_2)} \alpha_1^{(1-1/\theta_2)} \cdot 1/\theta_1 \alpha_2^{1/\theta_2}$

provided $x > x'' > x'$. Clearly $\overline{L}\rho_2(x) = \theta_2 \theta_1^{(1-1/\theta_2)} \alpha_1^{(1-1/\theta_2)} 1/\theta_1 \alpha_2^{1/\theta_2}$.

Similarly take $x_3 = \left[\frac{\rho_2 x^{(1-1/\theta_1)(1-1/\theta_2)}}{\alpha_3} \right]^{1/\theta_3}$ and proceed in this way up to x_{n-1} .

Then $\alpha_{n-1} x_{n-1}^{\theta_{n-1}} = \rho_{n-2} x^{(1-1/\theta_1) \dots (1-1/\theta_{n-2})} - \rho_{n-1} x^{(1-1/\theta_1) \dots (1-1/\theta_{n-1})}$.

Finally choose as x_n the integer just exceeding

$$\left\{ \frac{\rho_{n-1}}{\alpha_n} x^{(1-1/\theta_1) \dots (1-1/\theta_{n-1})} \right\}^{1/\theta_n} \text{ so that}$$

$$x_n = \left\{ \frac{\rho_{n-1}}{\alpha_n} x^{(1-1/\theta_1) \dots (1-1/\theta_{n-1})} \right\}^{1/\theta_n} + \epsilon_n, \quad 0 < \epsilon_n < 1$$

and hence

$$\begin{aligned} \alpha_n x_n^{\theta_n} &= \rho_{n-1} x^{(1-1/\theta_1) \dots (1-1/\theta_{n-1})} \\ &\quad \left[1 + \theta_n \epsilon_n \left\{ \frac{\rho_{n-1}}{\alpha_n} x^{(1-1/\theta_1) \dots (1-1/\theta_{n-1})} \right\}^{-1/\theta_n} (1 + \epsilon) \right] \\ &< \rho_{n-1} x^{(1-1/\theta_1) \dots (1-1/\theta_{n-1})} + C_0 (1 + \epsilon) x^{(1-1/\theta_1) \dots (1-1/\theta_n)} \dots \dots (n) \end{aligned}$$

where $C_0 = \theta_n \theta_{n-1}^{(1-1/\theta_n)}$ etc. and $\epsilon \rightarrow 0$ as $x \rightarrow \infty$.

Adding (1), (2), ..., (n) we get

$$x < \alpha_1 x_1^{\theta_1} + \alpha_2 x_2^{\theta_2} \dots + \alpha_n x_n^{\theta_n} < x + C_0 (1 + \epsilon) x^{(1-1/\theta_1) \dots (1-1/\theta_n)}$$

whenever $x > x_0(\alpha_1 \alpha_2 \dots \alpha_n, \theta_1, \theta_2, \dots, \theta_n, \epsilon)$.

Making the above selections in all possible different orders one can obtain the minimum value for C_0 . In the above proof we have not taken any $\epsilon_i = 0$, for in that case x itself becomes representable by the form.

If in the above theorem we take in particular

$$\alpha_1 = \alpha_2 \dots = \alpha_k = 1, \quad \theta_1 = \theta_2 = \theta_3 \dots = \theta_k = k$$

we get the following theorem.

THEOREM 3. Between x and $x + (1 + \epsilon) C x^{(1-1/k)^k}$, where C is a constant, $\epsilon > 0$, $x > x_0(\epsilon, k)$, there always exists an integer which can be expressed as a sum k integral k th powers.

My thanks are due to Dr. S. S. Pillai for suggesting to me some problems allied to those discussed above.

REFERENCE.

Bambah, R. P. and Chowla, S. (1947). On numbers which can be expressed as a sum of two squares. *Proc. Nat. Inst. of Sc. of India*, **13**, 101-103.

A PRELIMINARY ACCOUNT OF THE STRUCTURE OF THE CUTICLES OF *DICROIDIUM* (*THINNFELDIA*) FRONDS FROM THE MESOZOIC OF AUSTRALIA.*

By K. JACOB, D.Sc., F.N.I., and (MRS.) CHINNA JACOB, M.Sc., Ph.D.,
Geological Survey of India.

(Received 18th April, 1950.)

CONTENTS.

	Page
I. INTRODUCTION	101
II. GENERAL FEATURES OF <i>Dicroidium</i> CUTICLE	102
III. DESCRIPTION OF SPECIES	104
Alethopteroid fronds—Pinnate:	
<i>Dicroidium lancifolium</i> (Morris)	104
<i>Dicroidium acuta</i> (Walkom)	105
<i>Dicroidium narrabeenensis</i> (Dun MS.)	107
<i>Dicroidium eskensis</i> (Walkom)	111
<i>Dicroidium</i> sp. cf. <i>D. talbragarensis</i> (Walkom)	114
Odontopteroid fronds—Bipinnate:	
<i>Dicroidium feistmanteli</i> (Johnston)	116
<i>Dicroidium australis</i> sp. nov.	119
<i>Dicroidium walkomi</i> sp. nov.	122
IV. SUMMARY	125
V. BIBLIOGRAPHY	125

I. INTRODUCTION.

A small collection of *Dicroidium* (*Thinnfeldia*) fronds from the Mesozoic of Australia was kindly lent to one of us in 1946 by Dr. A. B. Walkom, Director, Australian National Museum, Sydney, for a detailed study of their cuticles. All the specimens yielded satisfactory preparations after the usual chemical treatment. This is a preliminary note and briefly deals with the structure of the cuticles of eight species of *Dicroidium* studied by us. A detailed paper supported by photomicrographs will be published shortly.

According to the suggestion already made by Gothan (12) and Antevs (14), we refer these southern forms of *Thinnfeldia* fronds, characteristic of the Glossopteris province, to the genus *Dicroidium*, mainly based on their geographical distribution as was done in the case of *Noeggerathiopsis* (*Cordaites*) and *Gondwanidium* (*Neuropteridium*). Walkom (17, 21) and Du Toit (27), however, prefer to retain the generic name *Thinnfeldia* to include the southern fronds also, while Thomas (33) and Jones and de Jersey (47) suggest *Dicroidium* to accommodate the southern *Thinnfeldia*. The question of nomenclature will be fully discussed in the subsequent paper.

Based on megascopic features the following species may be recognized in the present collection:—

Alethopteroid fronds : pinnate—

- (F 35803 a) *Dicroidium lancifolium* (Morris).
 ? *Dicroidium acuta* (Walkom).
 (F 41810) *Dicroidium narrabeenensis* (Dun MS.).
 (F 17822) *Dicroidium eskensis* (Walkom).
 (F 35803 b) *Dicroidium* sp. cf. *D. talbragarensis* (Walkom).

* Published by permission of the Director, Geological Survey of India.

Odontopteroid fronds: bipinnate—

(F 408) *Dicroidium feistmanteli* (Johnston).

There are two other bipinnate fronds (Figs. 20, 25) which may be compared with Walkom's *D. feistmanteli* (1925, Pl. XXIV, fig. 7; Pl. XXV, fig. 1). But the cuticles of these two forms (Figs. 21–24; 26, 27) which are totally different from each other do not agree with those of typical *D. feistmanteli* (Figs. 17–19). Hence they are placed in two new species. We have great pleasure in naming the smaller frond (F 16391) shown in Fig. 25 as *D. walkomi* after Dr. A. B. Walkom who kindly made this collection available for our study. The larger frond (F 17832) shown in Fig. 20 is named *D. australis*.

Brief descriptions of the cuticular structure of the southern fronds, *Dicroidium odontopteroides* (Seward, 03 and Gothan, 12), *D. feistmanteli* (Antevs, 13, 14) and *D. lancifolium* (Walkom, 17) have previously appeared. Thomas (33) has made a detailed study of the cuticles of *Dicroidium* fronds as well as those of the male and female fructifications suspected to belong to the same type of plant. The cuticles of some species of the northern *Thinnfeldia* have also been studied by Gothan (12), Antevs (14), and Harris (37).

Jones and de Jersey (47) suggest that *D. odontopteroides*, *D. acula*, *D. lancifolium*, *D. talbragarensis* and *D. feistmanteli* are probably con-specific. We are unable to agree with their suggestion. On the present evidence available to us from a cuticular study, we are inclined to consider that each one of the above species should be treated as distinct.

II. GENERAL FEATURES OF *Dicroidium* CUTICLE.

The cuticles of all the species of *Dicroidium* examined by us, show appreciable differences from each other in their thickness, arrangement of the cells, their average size, shape cutinization, in the distribution of the stomata per unit area and in the nature of the subsidiary cells.

But they all show a striking similarity with each other in the presence of the stomata in the upper and lower cuticles of the lamina and rachis; and in the size, shape, structure and orientation of the stomata.

Lamina—Upper cuticle:

In the low power, an apparent linear arrangement of the cells parallel to the secondary veins is clearly discernible. In some of the alethopteroid forms where the frequency of stomata is less, this arrangement is more definite. In all the forms the cells over the veins are inclined to be arranged in rows, the stomata being fewer in number in that region.

The cells are polygonal, usually 4–6 sided. They may be straight-walled with sharp angles or rounded corners. Striations due to uneven thickening are observed in the cells of almost all the species, but the nature of these striations varies in the different species. The more thickened areas appear as ridges and the thinner areas as lacunae. The walls of the cells are undulated in some species and in others straight-walled. In addition to faint striations, irregular pitting is noticed in one or two species. The thickness of the cell wall may vary from 3–5 μ . In a few species the cell walls are heavily cutinized.

Papillae or indications of them are seen in the cuticles of four species. In some they are raised; in one species they occur as flat structures present in most cells.

In the presence of irregularly oriented stomata both on the upper and lower cuticles and in the general shape, size and structure of the stomata, all the species agree. The distribution of stomatal groups in the areas between the forked veins is fairly noticeable in the alethopteroid fronds. Stomata may also be present over

the veins, but are few in number. In the odontopteroid fronds the number of stomata per unit area is greater than in the alethopteroid fronds. In the former the number per 1 mm. square area varies from 25-40, while in the latter it is only 5-20.

In their essential features, the structure of the stomata is similar in all the forms. They are more or less oval in shape with constrictions towards the poles, 40-45 μ long and 16-22 μ broad. The length of the pore varies from 16-23 μ . The sides of the guard cells facing the lateral subsidiary cells are generally thickened (Fig. 3*d*). They possess characteristic transverse extensions towards the pore (Fig. 3*t*). These transverse extensions and the polar regions of the guard cells (Fig. 3*p*) usually remain unthickened; in *D. feistmanteli* (Fig. 18) the whole of the guard cell is thin. In a few species the stomata are sunken.

Though the subsidiary cells (Florin's *Nebenzellen*, 1931) vary in shape, size and number, they show a general similarity in all the forms. The common features found in one species may be the exception in the other. Stomata with two subsidiary cells occupying the whole dorsal side of the two guard cells are commonly found in the majority of the species. The subsidiary cells may be crescent-shaped, 40-50 μ in length and 20-25 μ in width in the broadest part (Fig. 8*A*, *l.s.* 1), or may be angular and as broad as 50 μ (Fig. 8*A*, *l.s.* 2). Occasionally one or both the subsidiary cells may divide transversely (Fig. 3, *l.s.* 1-*l.s.* 4), in which case the lateral subsidiary cells may (Fig. 3, *l.s.* 3) or may not extend to the polar regions (Fig. 3, *l.s.* 4). Separate polar subsidiary cells also are not uncommon (Fig. 2, *p.s.*). In *D. feistmanteli* every stoma has highly cutinized subsidiary cells both in the lateral and the polar regions (Figs. 17, 18, *l.s.*, *l.s.* 1, *p.s.*).

Encircling cells (Florin's *Krantzzellen*, 1931) also may be found occasionally for one (Fig. 3, *l.e.*) or both the lateral subsidiary cells. But in *D. feistmanteli* (Figs. 17, 18 *l.e.*, *l.e.* 1) every stoma has highly cutinized encircling cells adjoining the lateral and sometimes the polar subsidiary cells. Both subsidiary cells and encircling cells may be thicker or thinner than the ordinary cells. They also show striations in many of the species.

Midrib—Upper cuticle:

The cells are shorter and more rectangular than those of the lamina; their linear arrangement is more pronounced.

The stomata per unit area may be the same as in the lamina or somewhat less.

Lamina—Lower cuticle:

The lower cuticle does not show any appreciable difference from the upper in some of the species. In others, they are thinner, the cells are slightly larger and the frequency of stomata is less than in the upper.

Rachis—Upper cuticle:

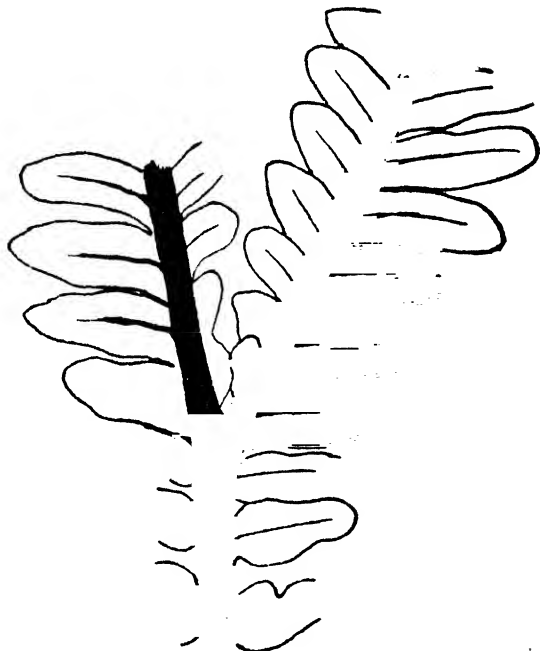
The cuticle thicker than that of the lamina. Cells arranged in definite longitudinal rows, longer in the middle part of the rachis, gradually become shorter and irregular in shape near the attachment of the lamina. The cells are striated in almost all the species. The cell-walls are more cutinized; they may be smooth or crenate irrespective of those of the lamina.

Stomata per unit area less, orientation transverse or irregular; the size may or may not be the same as in those of the lamina; guard cells uniformly thickened all round; subsidiary cells not specialized in the stomata of the middle region; no encircling cells present.

Rachis—Lower cuticle :

The cells are shorter and broader than those of the upper cuticle of the rachis. Rows irregular; cells 4-5 sided, irregular in shape and size, larger than those of the lamina; stomata per unit area more than in the upper cuticle of the rachis; subsidiary cells specialized.

III. DESCRIPTION OF SPECIES.

*Alethopteroid fronds—Pinnate :****Dicroidium lancifolium* (Morris). Figs. 1-3****Fig. 1 x ca 1***Dicroidium lancifolium.***FIG. 1.** Part of frond, F 35803a, \times ca. 1.

'Frond divides dichotomously into two linear pinnae which are inclined to one another at an acute angle. Pinnules vary in form with their position; the majority are elongate, tapering, with a rather acute tip, and have a distinct midrib which does not usually persist to the tip of the pinnule. The pinnules on the inner sides of the branches become smaller as the point of branching is approached, and gradually change from elongate acute to a rather ovate semi-circular or more or less rhomboidal shape, without a midrib, the veins arising directly from the rachis. The pinnules on the rachis below the junction may be of either type. The venation is alethopteroid, the secondary veins being given off from the midrib at a rather acute angle. In the basal portion of the pinnules some of the veins come directly from the rachis; the pinnules are decurrent and are connected by a narrow lamina along the rachis.' (Walkom, 17.)

The details of the frond shown in Fig. 1 tally with the description given by Walkom. It can also be compared closely with *D. lancifolium* figured by him in 1925 (Pl. XXVI, Fig. 2).

The cuticle of *D. lancifolium* is very briefly described by Walkom (25). As the details are not indicated either in his description or in the figures, attempt is not made here to compare our cuticle with those figured by Walkom.

Lamina—*Upper cuticle* (Figs. 2, 3):

Cuticle comparatively thick; general linear arrangement of the cells discernible; over the veins the cells are in rows; cells polygonal, varying in shape and size, faintly striated, striations parallel to the length of the cells. Average cell $65\mu \times 40\mu$, walls straight, 2.3μ thick. Raised papillae observed (Fig. 2, *p.a.*) in a few cells, $10-16\mu$ long.

Stomata $15-18$ per 1 mm. square area, irregularly oriented, $40-45\mu$ long, $20-25\mu$ broad. Pore $16-20\mu$ long. Thickened lateral walls of the guard cells measure $7-9\mu$. In a few stomata their free margin can be seen as in Bennettitalean stomata (Fig. 3, *d*). Transverse extensions present (Fig. 3, *t*). Polar regions not thickened (Fig. 3, *p*). Stomata appear sunken.

Subsidiary cells usually two (Fig. 2), lateral; may be crescent-shaped or angular; 3 or 4 also fairly common (Figs. 2, 3, *l.s.1-l.s.4*). Polar subsidiary cells also present in some (Fig. 2, *p.s.*). Encircling cells rare (Fig. 3, *l.e.*). Both subsidiary cells and encircling cells thinner than ordinary cells; striations parallel to the length of the cells.

Rachis—*Upper cuticle*: Not preserved.

Rachis—*Lower cuticle*:

Arrangement of cells more or less in rows, rectangular, very thickly cutinized, slightly smaller than those of the lamina; striations present; stomata irregularly oriented, $10-15$ per 1 mm. square area.

Locality and Horizon: Triassic shales, Benelong, N.S. Wales.

Dicroidium acuta (Walkom). Figs. 4-6

'Frond divides dichotomously into two linear pinnac; rachis strong. Pinnules some distance apart, long, narrow, tapering gradually to an acute tip, attached by the whole base, decurrent, joined by a narrow lamina along rachis. Venation alethopteroid, midrib prominent and persisting to the tip; secondary veins make an acute angle with the midrib. A few pinnules in the fork between the two branches are modified in shape on account of their position.' (Walkom, 17).

The frond shown in Fig. 4, though badly preserved, reveals the characteristic features of *D. acuta*. The midrib and veins are not clearly discernible.

Lamina—*Upper cuticle* (Figs. 5, 6):

Cuticle thick; the general linear arrangement of cells not well pronounced. However, the cells over the veins are in rows. They are of varying shape and size, polygonal; average cells $80\mu \times 65\mu$ in size, striated; striations forming short meshes; striations in one cell may or may not be parallel to those in the adjacent cells. Cell wall straight, no undulation, 3.4μ thick; papillae not observed.

Stomata $10-15$ per 1 mm. square area, irregularly oriented; average stoma $40\mu \times 20\mu$; pore 18μ in length. Structure of the stomata more or less as in other species. The thickened lateral walls of the guard cells may measure 9μ (Fig. 6, *d*). Transverse extensions (Fig. 6, *t*) may or may not be prominent. Polar regions (Fig. 6, *p*) unthickened. The lateral subsidiary cells are not differentiated from the ordinary cells either in cutinization or in the presence of striations (Fig. 6, *l.s.*); but they are smaller than ordinary cells, the corners more angular than rounded;

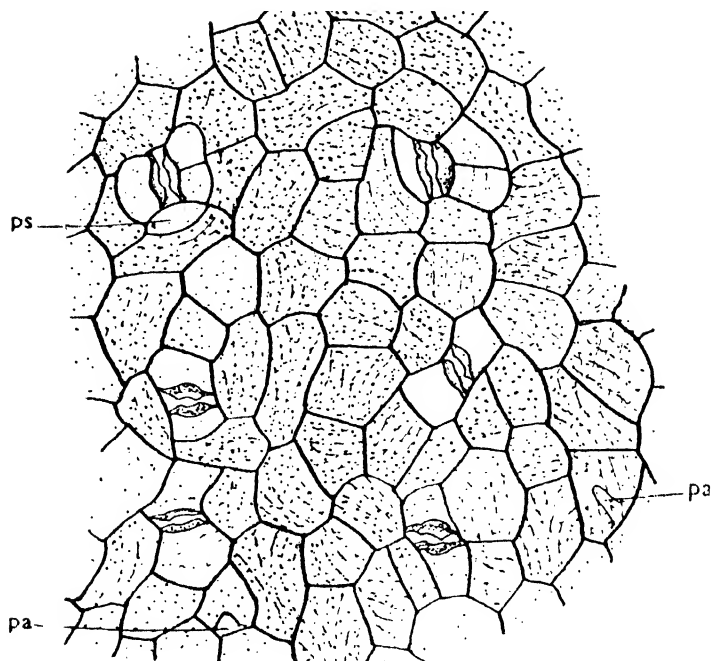
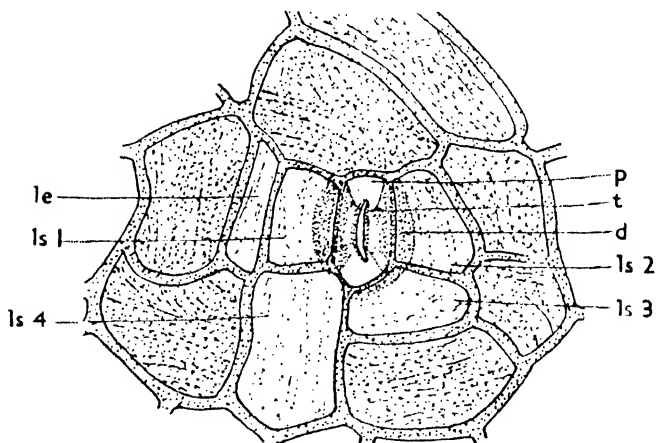
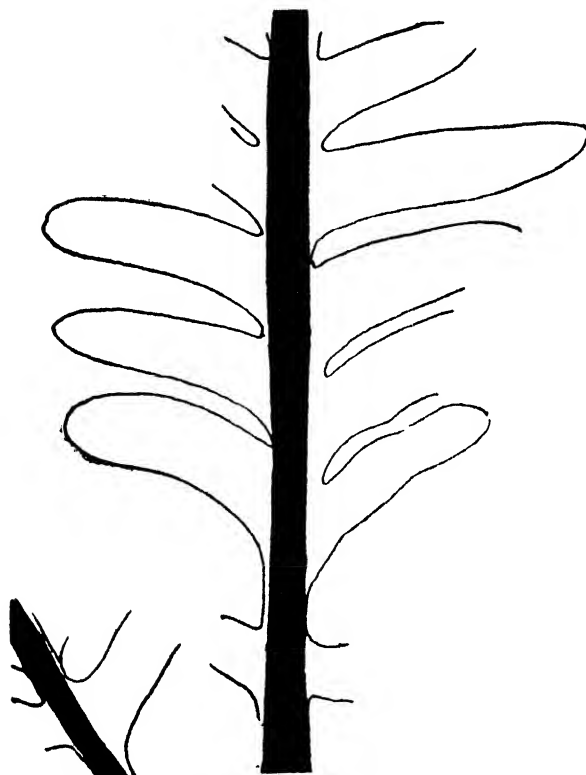
Fig. 2 $\times 190$ Fig. 3 $\times 430$ *Dicrodidium lancifolium*.

FIG. 2. Upper cuticle of lamina; *pa.* = papilla; *p.s.* = polar subsidiary cell; $\times 190$.

FIG. 3. Single stoma; *d.* = thickened lateral part of guard cell; *p.* = polar region of guard cell; *t.* = transverse extension of cuticle of guard cell; *ls.* 1-*ls.* 4 = lateral subsidiary cells; *le.* = encircling cell; $\times 430$.

Fig. 4 \times ca 1*Dicroidium acuta*.FIG. 4. Part of frond, \times ca. 1.

crescent-shaped subsidiary cells are also common; average lateral subsidiary cell $50\mu \times 25\mu$ in size.

Midrib—Upper cuticle:

Cells over the midrib arranged in regular rows parallel to the midrib, cells rectangular; stomata fewer in number.

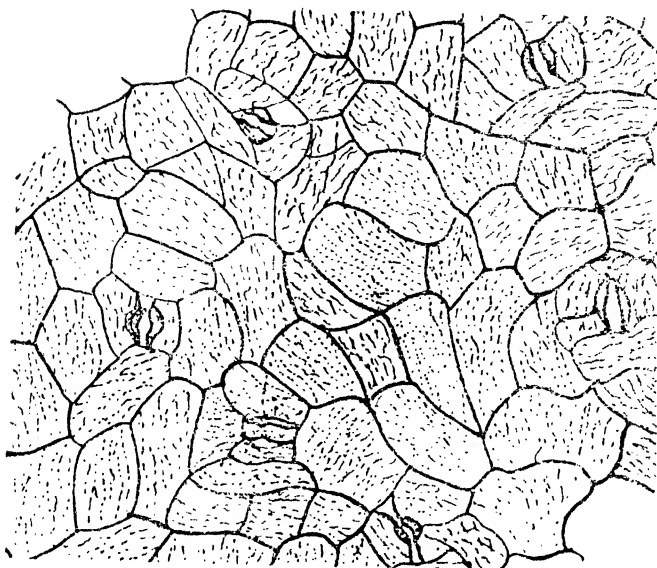
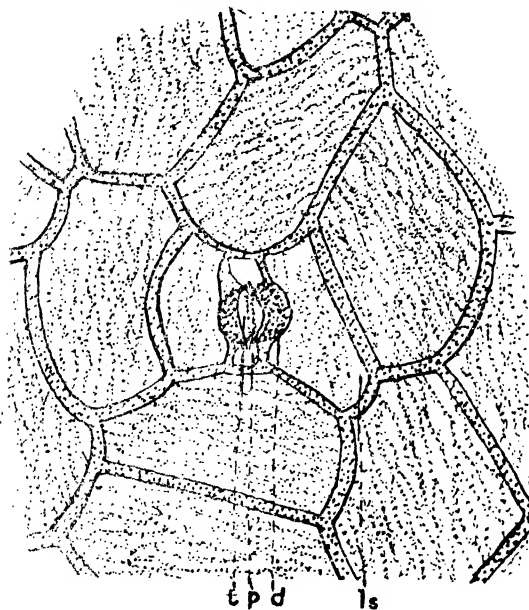
Rachis—cuticle: Under study.

Locality and Horizon: ? Triassic shales, ? Narrabeen, near Sydney, N.S. Wales.

***Dicroidium narrabeenensis* (Dun MS.). Figs. 7–9**

'Frond large, pinnate, dichotomous. Rachis strong, pinnules large, elongate, obtusely pointed, opposite or sub-opposite, with margins usually entire, occasionally broadly lobed. In the basal portion of the frond the pinnules are modified, being reniform to triangular and somewhat contracted at the base. The elongate pinnules have a prominent midrib, with secondary veins close, slightly curved, and branching. The basal pinnules have venation of the odontopteroid type.' (Walkom, 25).

Only a part of the frond is shown in Fig. 7. The basal portion is, however, not preserved.

Fig. 5 $\times 190$ Fig. 6 $\times 430$ *Dicroidium acuta.*FIG. 5. Upper cuticle of lamina, $\times 190$.FIG. 6. Single stoma; *d.* = thickened lateral part of guard cell; *p.* = polar region of guard cell; *t.* = transverse extension; *ls.* = subsidiary cell; $\times 430$.

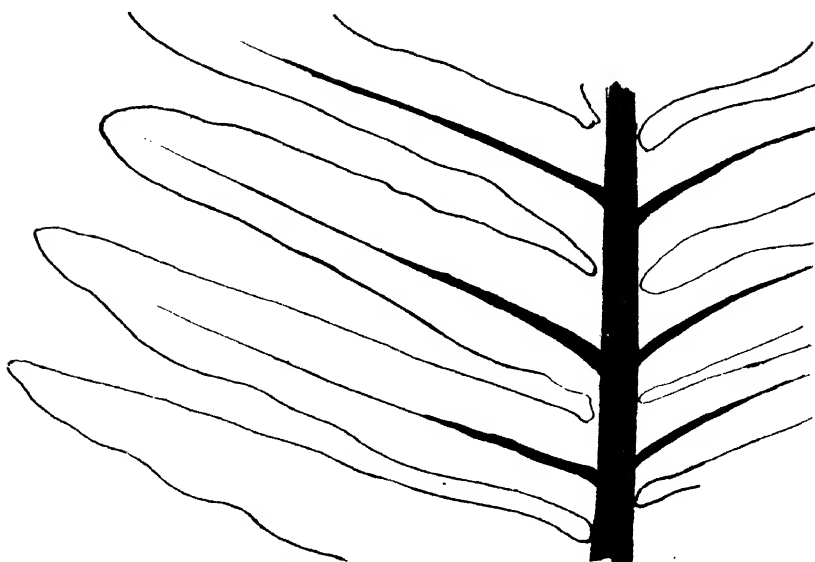


Fig. 7 \times ca 1

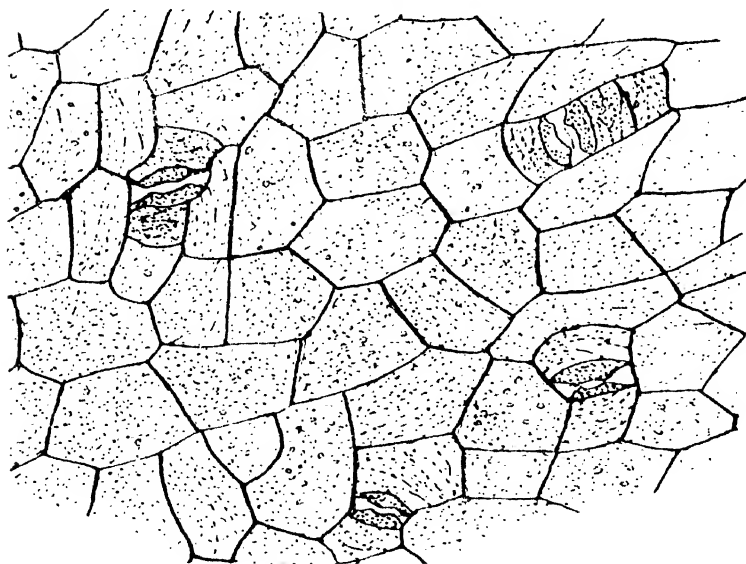


Fig. 8 \times 190

Dicroidium narrabeenensis.

FIG. 7. Part of frond, F 41810, \times ca. 1.

FIG. 8. Upper cuticle of lamina, \times 190.

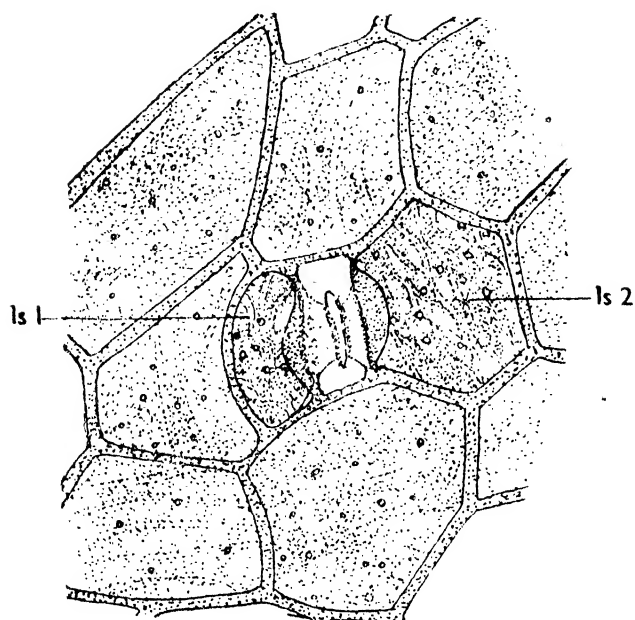
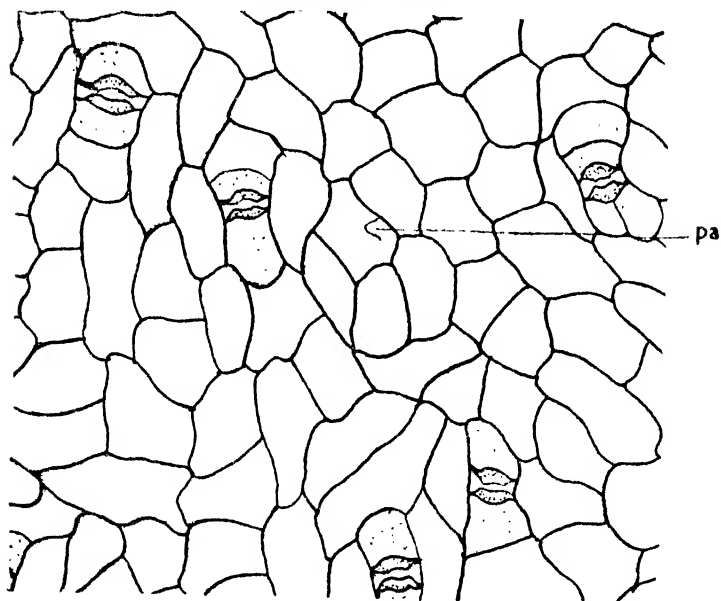
Fig. 8A $\times 430$ Fig. 9 $\times 190$ *Dicrodium narrabeenensis.*

FIG. 8A. Single stoma; *ls. 1* = crescent-shaped subsidiary cell; *ls. 2* = broad subsidiary cell; $\times 430$.

FIG. 9. Lower cuticle; *pa.* = papilla; $\times 190$.

Lamina—Upper cuticle (Figs. 8, 8A):

Cuticle moderately thick, cells arranged in apparent linear rows running parallel to the secondary veins. Cells 4–6 sided, irregular in size and shape, $50\text{--}100\mu \times 25\text{--}40\mu$ in size. Both parallel striations and fine pitting present. Short papillae preserved in a few cells.

Frequency of stomata 10–15 per 1 mm. square area, irregularly oriented and mostly confined to areas between the veins, $40\text{--}45\mu \times 16\text{--}25\mu$ in size; pore $16\text{--}22\mu$ long; thickened part of the guard cells $7\text{--}9\mu$ broad. Transverse extensions present. Polar regions unthickened.

Subsidiary cells usually two, lateral, crescent-shaped (Figs. 8, 8A, *l.s.* 1), $40\mu \times 20\mu$ in size. Stomata, with broader subsidiary cells (Figs. 8, 8A, *l.s.* 2) which may be $40\mu \times 50\mu$ in size, are also common. Occasionally 3 or 4 subsidiary cells are observed; polar cells also met with in certain cases. Encircling cells occasionally present. The subsidiary and encircling cells slightly more cutinized than the ordinary cells; striations which may form meshes are more prominent than in the ordinary cells.

Midrib—Upper cuticle:

Cells shorter, $65\mu \times 50\mu$ in size, more or less rectangular, arranged in rows parallel to the midrib. Frequency of stomata 10–12 per 1 mm. square area.

Lamina—Lower cuticle (Fig. 9):

Much thinner, cells elongated and rounded at corners as in *D. eskensis*. Striations very faint; pits present. Raised papillae in a few cells (Fig. 9, *pa.*). Subsidiary cells striated.

Rachis:

Cuticle not preserved.

The lower cuticle of the lamina of this species shows striking similarity with those of *D. eskensis* and *Dicroidium* sp. cf. *D. talbragarensis* in the general appearance, the apparent linear arrangement of the cells, and in the shape of the subsidiary cells.

Locality and Horizon: Triassic shales, Narrabeen, near Sydney, N.S. Wales.

***Dicroidium eskensis* (Walkom). Figs. 10–12**

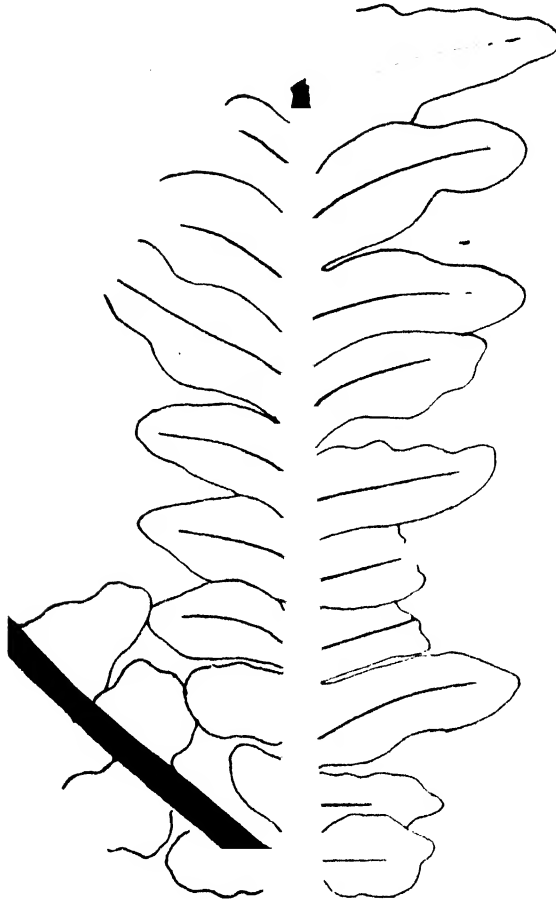
'Frond large, with strong, striated rachis. Pinnules large, robust, gradually tapering to rounded acute apex; upper half of lamina contracting at base, lower half broadening slightly and somewhat decurrent; midrib prominent becoming evanescent near apex; secondary veins make an acute angle ($20^\circ\text{--}50^\circ$) with midrib and divide, usually only once; a small number of veins at the base of the pinnule spring direct from the rachis.' (Walkom, 28).

The dichotomizing pinnate frond shown in Fig. 10 is typical of *D. eskensis*.

Lamina—Upper cuticle (Figs. 11, 12):

Cuticle thin. Linear arrangement of cells more pronounced; cells longer; corners rounded, striations not observed; irregular pits or fine pits present, size of cells $70\text{--}120\mu \times 40\text{--}50\mu$; cell walls straight, $3\text{--}5\mu$ thick.

Stomata only 5–8 per 1 mm. square area. Some appear in uniseriate bands; orientation irregular; $40\text{--}50\mu$ long and $20\text{--}30\mu$ broad; thickened area of the guard cells about 9μ broad (Fig. 12, *d.*).

Fig. 10 \times ca 1*Dicroidium eskensis.*FIG. 10. Part of frond, F 17822, \times ca. 1.

Subsidiary cells more cutinized than the ordinary cells, usually two, lateral (Figs. 11, 12, *l.s.*), with the longer axis transverse to the length of the pore, average size $40\mu \times 50\mu$, striations not present; polar subsidiary cells rare. Encircling cells (Fig. 12, *l.e.*) occasionally present.

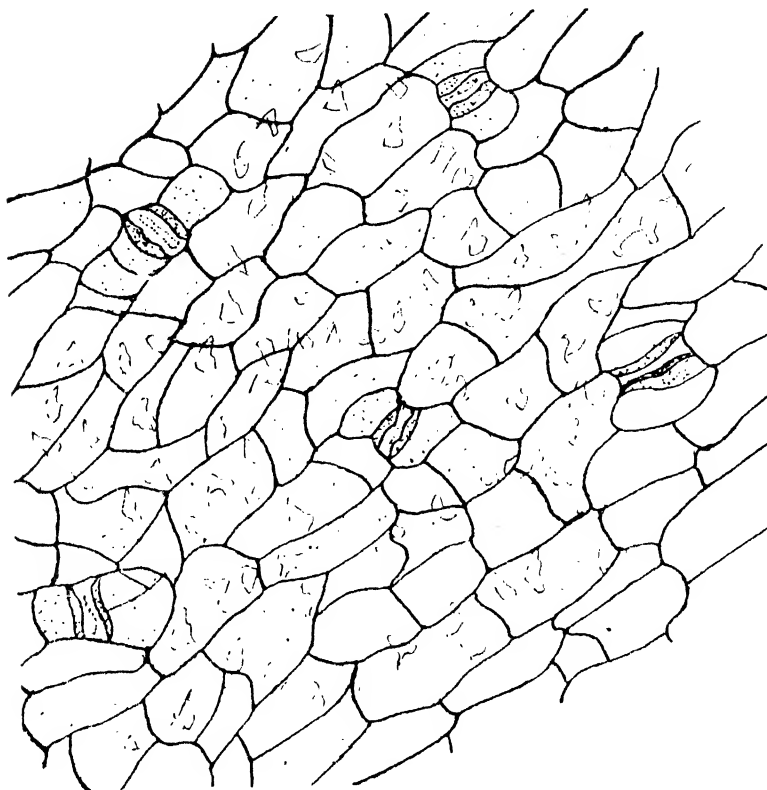
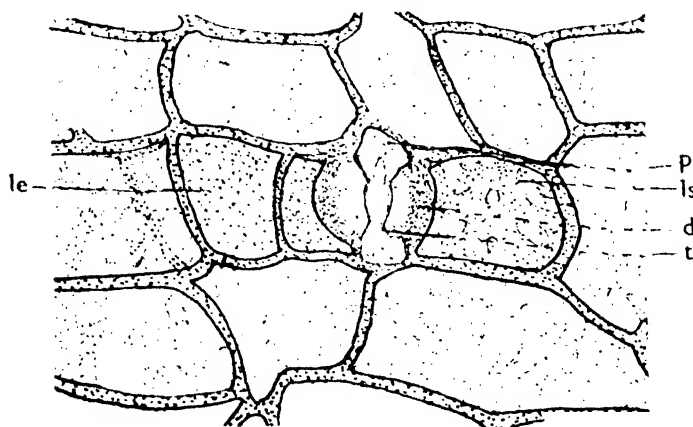
Midrib—Upper cuticle:

Cells more or less rectangular, arranged in rows parallel to the midrib, $90\mu \times 50\mu$, shorter than those of ordinary cells, corners not rounded.

Stomata 3–5 per 1 mm. square area.

Midrib—Lower cuticle:

Cells still smaller, $65\mu \times 50\mu$; stomata 5–8 per 1 mm. square area.

Fig. 11 $\times 190$ Fig. 12 $\times 430$ *Dicroidium eskensis.*FIG. 11. Upper cuticle of lamina, $\times 190$.FIG. 12. Single stoma; *d.* = thickened lateral part of guard cell; *p.* = polar region of guard cell; *t.* = transverse extension; *l.s.* = broad subsidiary cell; *l.e.* = encircling cell; $\times 430$.

Rachis—Upper cuticle :

Cells in definite rows, majority short, 30–150 μ long and 50 μ broad. Heavily cutinized cell wall 10 μ thick.

Stomata 2-3, irregularly oriented, guard cells thick all round. Specialized subsidiary cells as in lamina may or may not be present, more cutinized.

Rachis—Lower cuticle :

Cells shorter and polygonal, arranged in irregular rows; stomata 5-10 per 1 mm. square area.

The upper cuticle of this species can be compared with the lower of *D. narrabeenensis* in its general appearance, the apparent linear arrangement of the cells in rows, the shape of the cells, the somewhat indefinite differentiation of the stomatal and non-stomatal bands, the fewer number of stomata per unit area and in the shape and size of the subsidiary cells.

Locality and Horizon : Triassic shales, Narrabeen, near Sydney, N.S. Wales.

***Dicroidium* sp. cf. *D. talbragarensis* (Walkom). Figs. 13-15.**

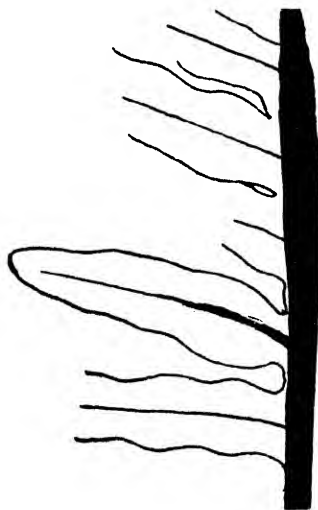


Fig. 13 x ca 1

Dicroidium sp. cf. *D. talbragarensis*.

FIG. 13. Small part of frond, F 35803b, \times ca. 1.

'Frond bipinnate, pinnæ variable—some of the same type as *T. lancifolia*, some with markedly wavy margins, and others with the lamina distinctly divided after the manner of *T. feistmanteli*. Pinnæ narrow at base and attached to rachis only by narrow portion. The venation in the simple pinnæ is alethopteroid, while in those pinnæ resembling *T. feistmanteli*, the pinnules have the typical odontopteroid venation.' (Walkom, 21).

Walkom created this species to accommodate two markedly different types of fronds; one, pinnate with alethopteroid venation and the other bipinnate with odontopteroid venation.

The frond (Fig. 13) may be compared to the pinnate forms of the above species except in the absence of the extremely constricted base.

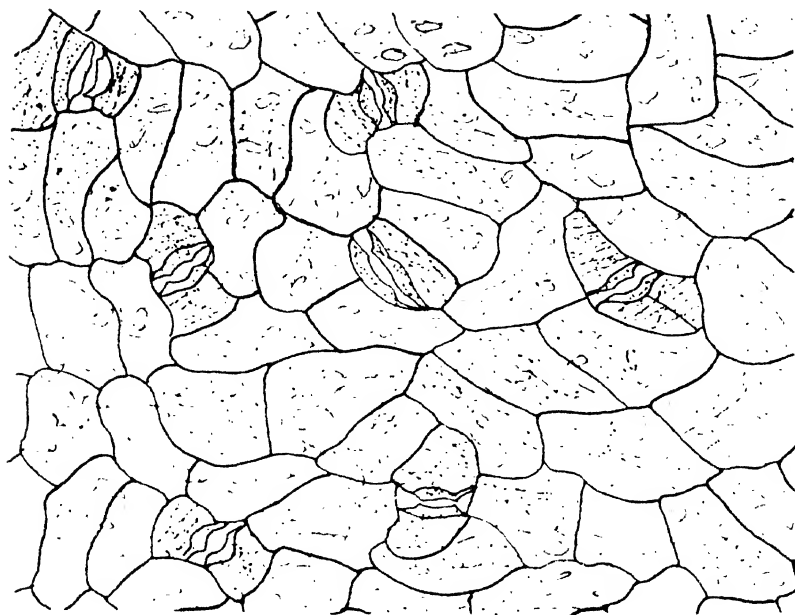


Fig. 14 $\times 190$

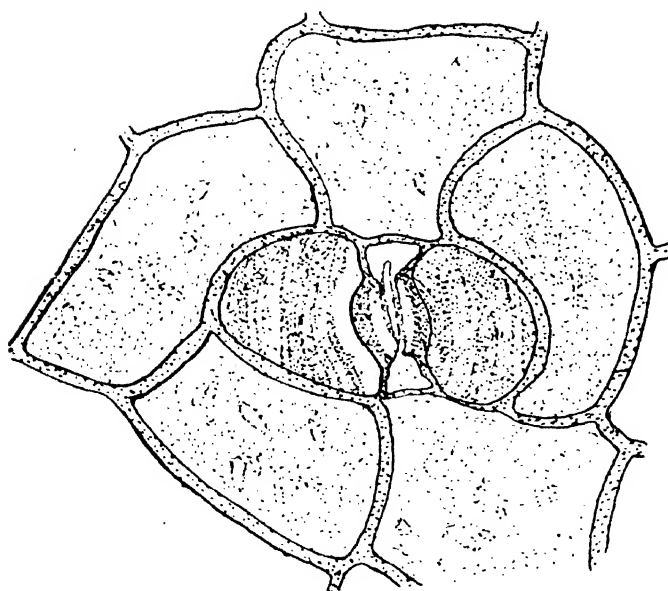


Fig. 15 $\times 430$

Dicroidium sp. cf. *D. talbragarensis*.

FIG. 14. Upper cuticle of lamina, $\times 190$.

FIG. 15. Single stoma, $\times 430$.

Lamina—*Upper cuticle* (Figs. 14, 15):

Cuticle moderately thick; arrangement of cells in fairly pronounced rows; shape of cells similar to those in *D. eskensis*, but striations present, pits more or less oval, average size of cell $100\mu \times 50\mu$.

Stomata 15–20 per 1 mm. square area, orientation, size and shape of the stomata as in other species; 2, 3 or 4 subsidiary cells fairly common. Encircling cells also present; both striated as in *D. narrabeenensis*.

Though this cuticle resembles those of *D. narrabeenensis* and *D. eskensis* in some respects, it cannot be closely compared with either of them. It appears to be a form intermediate between the above two.

Locality and Horizon : *Triassic shales, Benelong, N.S. Wales.*

***Dicroidium feistmanteli* (Johnston). Figs. 16–19**

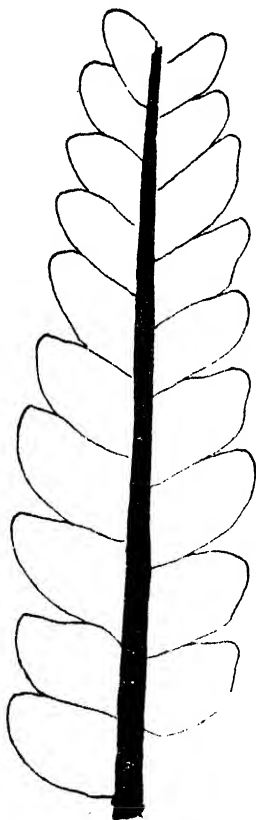


Fig. 16 x ca 1

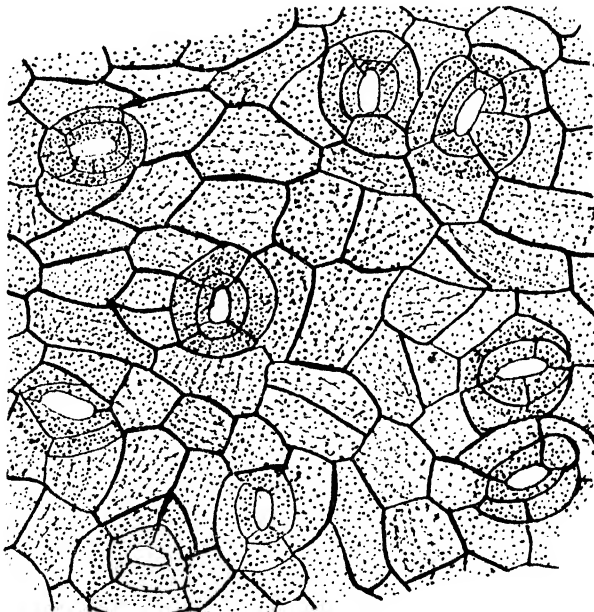


Fig 17 x 190

Dicroidium feistmanteli.

FIG. 16. Part of a pinna, F 408, \times ca. 1.

FIG. 17. Upper cuticle of lamina, \times 190.

'Frond bipinnate, paripinnate with a dichotomous rachis; apex is formed by a dichotomous branching of the rachis. Pinnae elongate, gradually tapering, alternate or opposite. Pinnules

rhombic, ovate or semicircular, thick, attached by whole of base and connected by very narrow lamina along the rachis. Venation odontopteroid, the veins springing directly from the rachis and dividing once or twice before reaching the pinnae, but in this position they may be slightly contracted at the base.' (Walkom, 17).

In our specimen (Fig. 16) only one pinna is preserved. In its external features it shows the characteristics of a pinna of *D. feistmanteli*. It is paripinnate; the basal pinnules on either side of the midrib are similar and are larger than those above indicating that it is most probably not a branch of the dichotomizing frond of *D. odontopteroides*. Further, its cuticle closely resembles that of *D. feistmanteli* described by Antevs (13, 14) except in the absence of papillae.

Lamina—Upper cuticle (Figs. 17, 18):

Cuticle more heavily cutinized than in any other species described. Arrangement of cells irregular; cells polygonal, of varying shape and size, $60-80\mu$ long and about 50μ broad, parallel striations clearly seen in most of the cells; in others, faint or absent. Walls straight, $3-5\mu$ thick, strongly cutinized. Papillae or indications of them not observed.

Distribution of stomata, 35–40 per 1 mm. square, irregularly oriented. Stomata $40-45\mu$ long and $20-23\mu$ broad; pore $16-20\mu$ long; guard cells (Fig. 18, *g*) unique in being uniformly thin unlike those in the other forms where their lateral sides are much thickened. However, the outline of the guard cells with their transverse extensions (Fig. 18, *t*) can be clearly made out.

According to Antevs (13), 'they are surrounded by 4–7 "Wallzellen", whose outer walls form a thick circle. The inner walls as well as the radial ones are, on the contrary, thin and lie a little immersed. The guard cells are not preserved.' The guard cells in our preparations are seen preserved in all the stomata (Figs. 17, 18, *g*); but due to their extreme thinness, they are very inconspicuous inside the ring of the heavily cutinized subsidiary and encircling cells. In this species the stomata are much sunken.

The stoma of this species is unique in yet another respect in having two rings of highly cutinized specialized cells: The inner ring ($6-9\mu$ broad) consists of 4–6 (4 being more common) subsidiary cells; the two laterals may be $65\mu \times 8\mu$ in size and the polars $25\mu \times 8\mu$, if their encircling cells are present; otherwise (*p.s.*), $25\mu \times 20\mu$ in size. Or the laterals may divide transversely forming four cells (Fig. 18, *l.s.-l.s. 1*), some of which may extend to the polar region (Fig. 18, *l.s. 1*). The laterals also are broader in case they have no encircling cells. The outer, inner and radial walls of these cells are apparently thinner than those of the ordinary cells; the cells are more heavily cutinized; striations transverse.

The outer ring ($10-12\mu$ broad) consists of the encircling cells (Fig. 18, *l.e., l.e. 1*) of the lateral subsidiary cells and the broad polar subsidiary cells, if the latter have no encircling cells; for, only occasionally we find encircling cells for one or both the polar subsidiary cells. In the case of the lateral subsidiaries, however, only occasionally they are found devoid of encircling cells; the walls are not thicker than those of the ordinary cells, but they are heavily cutinized. The breadth of these cells are slightly more than their subsidiary cells.

Rachis—Upper cuticle (Fig. 19):

Cells arranged in longitudinal rows, $60\mu \times 70\mu$ long and $40\mu \times 45\mu$ broad. Striations are prominent. Walls different from those of the lamina in their crenate appearance; 6–8 irregularly oriented stomata per 1 mm. square area, smaller than those of the lamina; subsidiary cells similar to ordinary cells; encircling cells absent; towards the lamina where the frequency of stomata (8–15) is higher, a ring of subsidiary cells present.

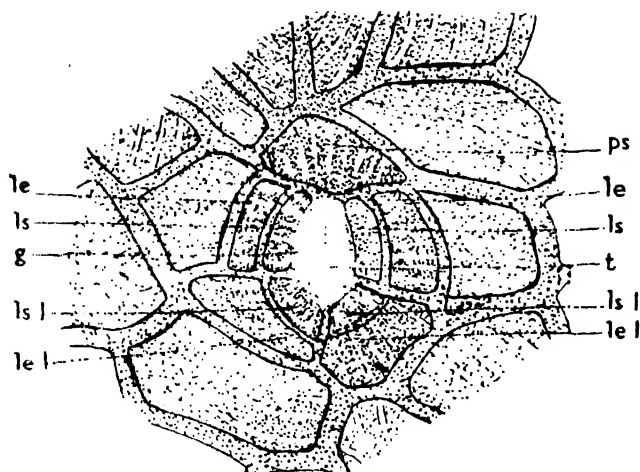
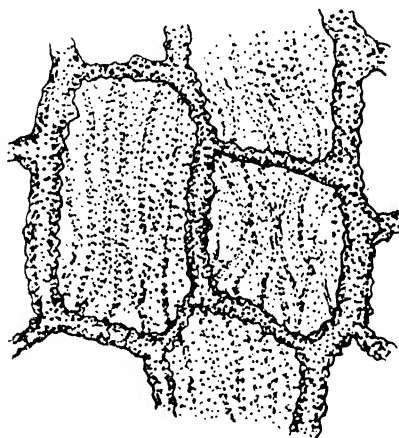
Fig. 18 $\times 430$ Fig. 19 $\times 430$ *Dicrodium feistmanteli.*

FIG. 18. Single stoma; *g.* = guard cell; *t.* = transverse extension; *l.s.*—*l.s.* 1 = lateral subsidiary cells; *l.e.*—*l.e.* 1 = lateral encircling cells; *p.s.* = broad polar subsidiary cell which has no encircling cell; $\times 430$.

FIG. 19. A few rectangular striated cells of the upper cuticle of rachis showing crenate wall; $\times 430$.

Rachis—Lower cuticle :

Cells shorter and broader; frequency of stomata higher (10–15); regular rings of subsidiary and encircling cells.

The cells of the rachis of this species show a slight resemblance to those of the lamina in *D. australis* (Fig. 21) in their undulating cell-walls and striated cells. But the similarity ends there.

Locality and Horizon : Wianamatta shales, McDonald Town, N.S. Wales.

***Dicroidium australis* sp. nov. Figs. 20–24.**

The frond shown in Fig. 20 is only partly preserved. The basal and apical portions of the rachis, the region of forking and the terminal regions of the larger pinnae are not preserved. However, it can be made out that it is a large bipinnate frond. The simple pinnae between the forked branches are 2 cm. long and 1.5 cm. broad. They have constricted bases and pointed apices. The margin is entire. The venation is essentially of the odontopteroid type; but an indication of midrib is vaguely visible just at the base of the pinnae.

Though the tip of none of the larger pinnae is preserved, it can be made out that originally they were at least as long as 10 cm., and about 2 cm. broad at the base. The basal parts are deeply lobed into ovate segments, the latter becoming smaller towards the apex; the upper part is simple with wavy margin. The pinnae have thick prominent midrib; veins odontopteroid in the ultimate segments; the basal lobes receive veins both from the midrib and the rachis.

On a casual examination the frond shows a close resemblance with *D. feistmanteli* figured by Walkom in 1925 (Pl. XXIV, Fig. 7). However, it varies from the typical fronds of *D. feistmanteli* in having only lobes instead of pinnules. Further, the upper part of the pinnae is simple with crenate and wavy margin. The cuticular structure is also different from that of *D. feistmanteli* (Figs. 16–19). Hence this frond is placed in a new species, *D. australis*.

Diagnosis :

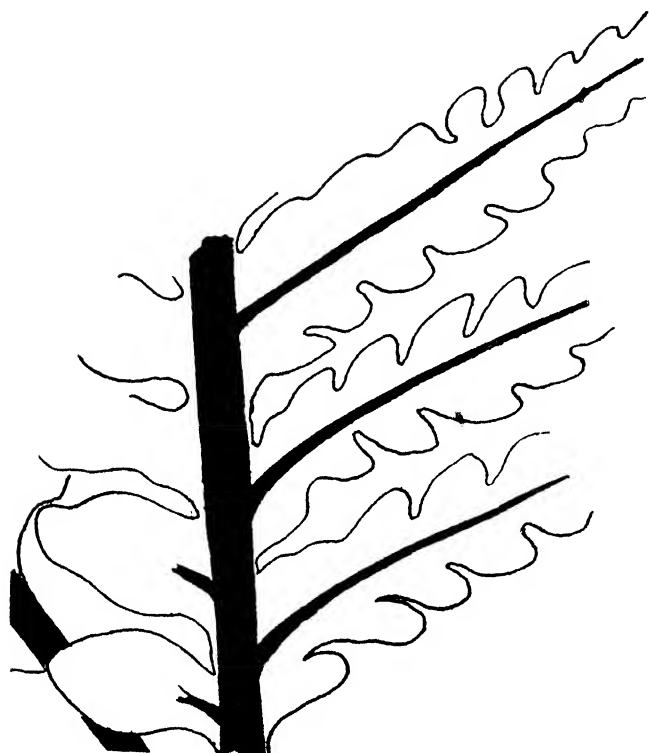
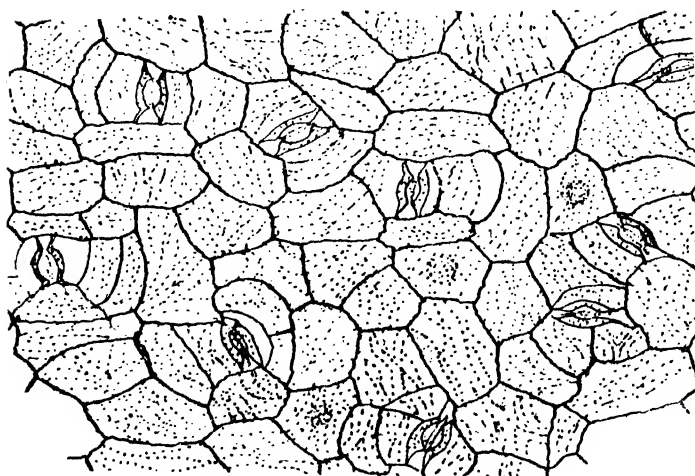
Frond bipinnate, rachis dichotomizing. Pinnae between the forked region simple, 2 cm. long and 1.5 cm. broad; margin entire, base constricted; venation odontopteroid; vague indication of a midrib just at the base; longer pinnae alternate or opposite, about 10 cm. long and 2 cm. broad at the base; basal part deeply lobed into ovate segments; apical region not lobed, wavy to entire. Pinnae with a definite midrib; venation odontopteroid in the ultimate segments; veins to the basal lobes arise both from the rachis and the midrib. Structure of the lower and upper cuticle of the lamina essentially the same; cuticle thick, cells polygonal, varying in shape and size; average cell $80\mu \times 50\mu$, striated; striations converge to the middle of the cells in most cases and at the point of convergence, a single papilla is present. In cells where striations run parallel, no papillae observed. Walls undulating. Stomata *Dicroidium* type, 20–25 per 1 mm. square area. Cells of the upper cuticle of rachis in longitudinal rows; striated, striations parallel to the length of the cells, undulations faint; stomata fewer in number. Cells of the lower cuticle of rachis polygonal, in irregular rows.

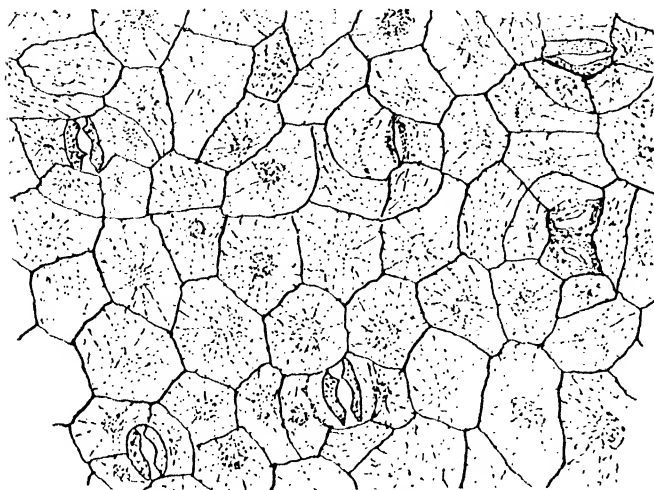
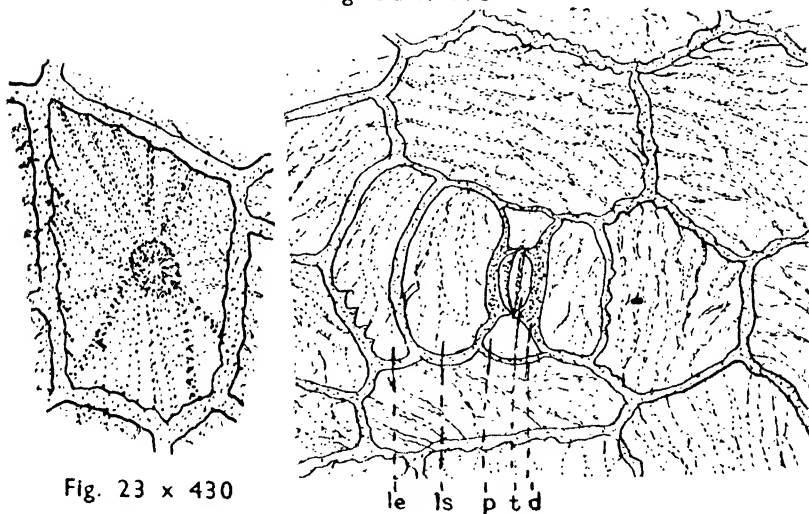
Lamina—Upper cuticle (Figs. 21–24):

Cuticle moderately thick. Cells irregularly arranged, polygonal, not uniform in shape and size, $60\text{--}80\mu \times 40\text{--}60\mu$. Cell wall appears undulating due to uneven thickening. Wall $2\text{--}3\mu$ thick. Cells striated; in many the striations converge to the centre where a single papilla is observed above the point of convergence (Figs. 21–23). In cells where the striations do not converge but run more or less parallel from wall to wall, papillae are absent (Figs. 21, 24).

Stomata about 20–25 per 1 mm. square, irregularly oriented, $40\text{--}45\mu$ long and $20\text{--}23\mu$ broad. Pore $16\text{--}20\mu$ long. Thickened dorsal side of the guard cells $4\text{--}6\mu$ (Fig. 24, d); polar region unthickened (*p.*); transverse extension present (*t.*).

Many stomata have two lateral subsidiary cells (Figs. 21, 22, 24, *l.s.*), $40\mu \times 25\text{--}30\mu$ in size; 3–4 subsidiary cells also very common, more or less extending to the

Fig. 20 \times ca 1Fig. 21 \times 190*Dicroidium australis* sp. nov.FIG. 20. Part of frond, F 17832, \times ca. 1.FIG. 21. Upper cuticle of lamina; striations more or less parallel, majority without papillae. \times 190.

Fig. 22 $\times 190$ Fig. 23 $\times 430$ Fig. 24 $\times 430$ *Dicroidium australis* sp. nov.

- FIG. 22.** Upper cuticle of lamina, striations converge to the centre of cell where a single papilla present; median papilla on subsidiary cell also; $\times 190$.
FIG. 23. Single cell showing striations and papilla; $\times 430$.
FIG. 24. Single stoma; *d* = thickened lateral part of guard cell; *p* = polar region of guard cell; *t* = transverse extension; *l.e.* = lateral subsidiary cell; *l.e.* = lateral encircling cell; $\times 430$.

polar regions forming a ring round the stoma; occasionally stomata with clear polar subsidiary cells are observed.

Encircling cells are common (Fig. 24, *l.e.*). Both subsidiary cells and encircling cells are striated with undulating walls; median papillae observed in many (Fig. 22).

Rachis—Upper cuticle:

More thickened than those of the lamina, cells longer and arranged in longitudinal rows. Middle row of cells $110\text{--}112\mu \times 25\text{--}30\mu$. Towards either side, the cells shorter and broader. Cell walls only $2\text{--}3\mu$ thick; undulations very faint or absent. Striations on cells quite prominent and run parallel to the length of the cells.

Stomata 3–5 per 1 mm. square area, smaller and irregularly oriented; guard cells heavily cutinized all round; transverse thickening not prominent. No specialized subsidiary cells.

Rachis—Lower cuticle:

Cells shorter and broader, irregular in shape and size; stomata of greater frequency than in the upper cuticle; guard cells uniformly cutinized all round. Ring of 4–6 unspecialized subsidiary cells, also heavily cutinized.

The cuticle obtained by Thomas (33, fig. 52 *b*) from the frond described by him as *Dicroidium* sp. cf. *D. feistmanteli* (33, fig. 50) shows identical features with those of *D. australis*. In our opinion Thomas' frond belongs to *D. australis*.

Locality and Horizon: Triassic shales, Narrabeen, near Sydney, N.S. Wales.

***Dicroidium walkomi* sp. nov.** Figs. 25–27.

The frond (Fig. 25) assigned to this new species also is partly preserved. One branch of the dichotomizing rachis is preserved with a few incomplete pinnae on either side.

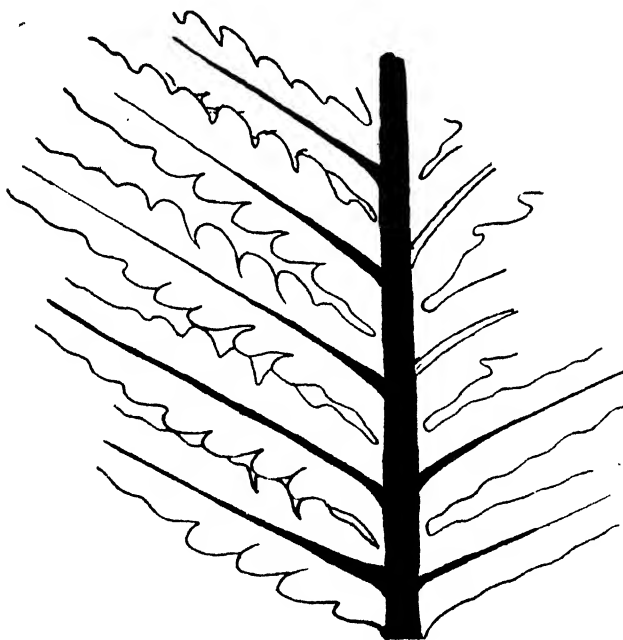


Fig. 25 \times ca 1

Dicroidium walkomi sp. nov.

FIG. 25. Part of frond, F 16391, \times ca. 1.

The rachis is 3–4 mm. broad. Basal pinnules on one side are simple and smaller than those opposite, indicating that the simple pinnae occupy the position just above the forked region of the rachis. These simple pinnae, about 3–3.5 cm. long and 1 cm. broad, resemble those of *D. talbragarensis* in their shape, size and venation. The base is not constricted; margin wavy. There is a definite midrib, persisting to the apex and giving rise to forked secondary veins. The apex is not preserved.

The longer pinnae are sub-opposite 6 cm. long and 1–1.5 cm. broad at the base. The basal parts have ovate lobes. Towards the apex the lobes are less definite and nearer the apex the margin is wavy as in the case of *D. australis*. The midrib is strong. The venation of the lobes is odontopteroid.

Though this frond could be compared with Walkom's *D. feistmanteli* (1925, Pl. XXV, fig. 1) in megascopic features, it differs from typical *D. feistmanteli* in its smaller size, in the absence of definite pinnules with the lamina only incompletely divided gradually giving rise to wavy margins in the apical half of the longer pinnae, and further, in the alethopteroid venation of the simple pinnae in the region of forking.

From *D. australis* it differs in the smaller size of the frond and the alethopteroid venation of the simple pinna over the forked region.

The cuticle of both *D. feistmanteli* and *D. australis* are structurally different from that of *D. walkomi*.

For reasons given above, we suggest the institution of a new species, *D. walkomi*, to accommodate this form.

Diagnosis:

Frond bipinnate; rachis dichotomizing. Pinna above the forked region simple, 3–3.5 cm. long, 1 cm. broad; base broad without constriction, margin wavy or entire; venation alethopteroid. Longer pinnae sub-opposite, 6 cm. long and 1.5 cm. broad at the base, without constriction; basal region with definite ovate lobes, apical region showing wavy margin of the lamina. Midrib fairly thick; venation of lobes odontopteroid; cuticle thick, linear arrangement of cells less pronounced, walls straight. Stomata *Dicroidium* type, 25–30 per 1 mm. square area; subsidiary cells 2–4, very thin.

Lamina—Upper cuticle (Figs. 26, 27):

Cuticle thick, cells in irregular rows, short and broad, of varying shape, striated, size $30\text{--}50\mu \times 30\text{--}50\mu$; walls straight, $2\text{--}3\mu$ in thickness.

Stomata 25–30 per 1 mm. square area, $45\text{--}50\mu \times 16\text{--}18\mu$ in size; pore $20\text{--}24\mu$. Dorsal wall of the guard cells 4μ thick (Fig. 27, d); transverse thickening not very prominent (*t.*); polar regions unthickened (*p.*).

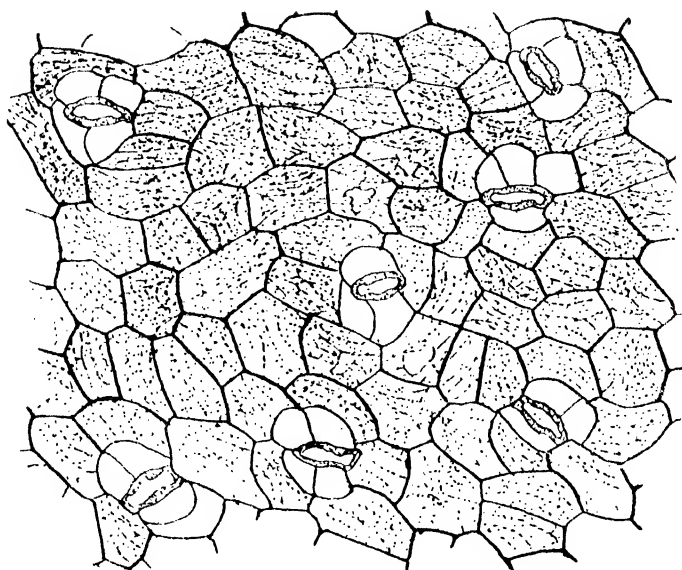
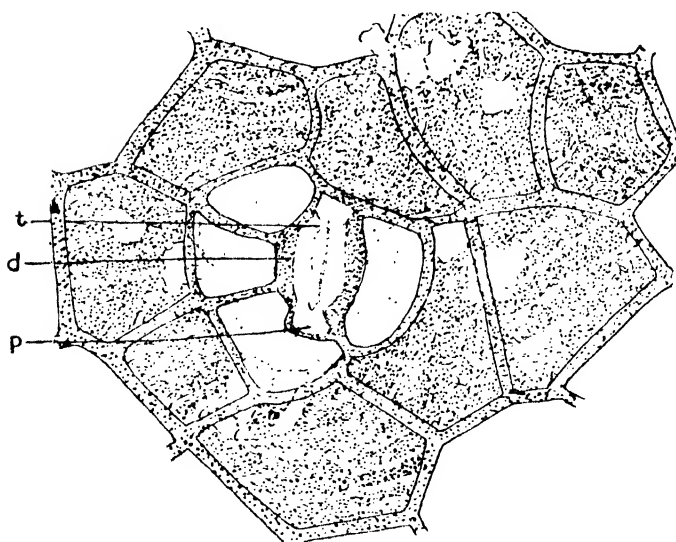
Subsidiary cells may be two, lateral and crescent-shaped. $50\mu \times 16\mu$ in size; 3 or 4 subsidiary cells very common (Figs. 26, 27); occasionally polar subsidiary cells also present; subsidiary cells much thinner than the ordinary cells; encircling cells very rare. Striations not observed.

Midrib—Upper cuticle:

Cells very short and mostly rectangular in shape, smaller than those of the lamina; walls slightly more cutinized; stomata about 20 per 1 mm. square area.

Rachis—Upper cuticle:

Cells in the region of the midrib arranged in rows, rectangular to polygonal, $100\mu \times 50\mu$ in size; wall 10μ in thickness; towards the periphery the rows of cells

Fig. 26 $\times 190$ Fig. 27 $\times 430$ *Dicroidium walkomi* sp. nov.FIG. 26. Upper cuticle of lamina, $\times 190$.FIG. 27. Single stoma; *d.* = lateral part of guard cell; *p.* = polar region of guard cell; *t.* = transverse extension; $\times 430$.

become irregular as also their shape and size; striations present. Stomata 10–12 per 1 mm. square area, usually larger, $60\mu \times 30\mu$; subsidiary cells thin.

Rachis—*Lower cuticle* :

Cells smaller in size than those of the upper cuticle, walls less thickened; striations not prominent.

Stomata 20–25 per 1 mm. square area, large as in the upper cuticle of the rachis.

Locality and Horizon : *Triassic shales*, Narrabeen, Manly, N.S. Wales.

AFFINITY

The earlier workers have included *Thinnfeldia* under the Filicales. Schenk (67) and Antevs (14) have raised this group to a position intermediate between the ferns and the gymnosperms. Seward (10, 31) was the first to include *Thinnfeldia* under the pteridosperms. But when Walkom (17) discovered fertile fronds of *Thinnfeldia* he instituted a new family the *Thinnfeldiaceae* the sporangia of which, according to him, showed affinities both with the Gleicheniaceae and the Marattiaceae. Du Toit (27) followed Walkom's suggestion and included *Thinnfeldia* fronds under the Filicales. Hamshaw Thomas (33), however, could prove with convincing evidence that *Dicroidium* (*Thinnfeldia*) belonged to Pteridospermae. He discovered also detached male and female fructifications lying in close association with *Dicroidium* and allied fronds from the Mesozoic of S. Africa. By their cuticular resemblance he has suggested that both the fructifications and the leaves belonged to the same type of plants.

It may be mentioned here that our study of the *Dicroidium* stoma has shown that it is typically gymnospermous. Although in certain respects it recalls some characteristics of the Bennettitalean stoma on the one hand, and the *Ctenis* group of the non-Bennettitalean fossil Cycadophyta on the other, it has been found to be distinct from those groups in many respects. The affinities of the *Dicroidium* stoma will be discussed in full in the detailed paper.

IV. SUMMARY.

The following species of *Dicroidium* (*Thinnfeldia*) have been recognized in a small collection of fronds from the Mesozoic of Australia, kindly lent by Dr. A. B. Walkom, Director, Australian National Museum, Sydney :

D. lancifolium (Morris), *D. acuta* (Walkom), *D. narrabeenensis* (Dun), *D. eskensis* (Walkom), *Dicroidium* sp. cf. *D. talbragarensis* (Walkom), and *D. feistmanteli* (Johuston).

Two new species, *D. australis* and *D. walkomi*, have been instituted based mainly on their cuticular structure.

The cuticles of the above species are briefly described.

We are grateful to Dr. W. D. West, C.I.E., Director, Geological Survey of India, for giving us all facilities for palaeobotanical research and to Dr. A. B. Walkom, Director, Australian National Museum, Sydney, for kindly placing the material at our disposal.

V. BIBLIOGRAPHY.

- Antevs, E. (1913). Some Mesozoic plants. Results of Dr. E. Mjöberg's Swedish Scientific Expeditions to Australia, 1910–1913. *K. Svenska Vet. Akad. Handl.*, Bd. 52, No. 5, 1–6.
 — (1914). Die Gattungen *Thinnfeldia* Ett. und *Dicroidium* Goth. *K. Svenska Vet. Akad. Handl.*, Bd. 51, No. 6, 1–71.
 Du Toit, A. L. (1927). The fossil flora of the Upper Karroo Beds. *Ann. S. Afr. Museum*, 22, 328–340.
 Feistmantel, O. (1890). Geological and Palaeontological relations of the Coal and Plant-bearing beds of Palaeozoic and Mesozoic age in Eastern Australia and Tasmania, with special reference to the fossil flora. *Mem. Geol. Surv. N.S.W., Pal.*, No. 3, 101–107.

- Florin, R. (1931). Untersuchungen zur Stammesgeschichte der Coniferales und Cordaitales. *K. Svenska Vet. Akad. Handl.*, Bd. 10, No. 1, 11-24.
- Gothan, W. (1912). Über die Gattung *Thinnfeldia* Ettingshausen. *Abh. Naturhist. Gesell. Nürnberg*, Bd. XIX, 2, 68-80.
- Harris, T. M. (1932). The fossil flora of Scoresby Sound, East Greenland, Pt. 2: Description of seed plants *incertae sedis* together with a discussion of certain Cycadophyte cuticles. *Meddl. Grønland*, Bd. 85, Nr. 3, 71-94.
- (1937). The fossil flora of Scoresby Sound, East Greenland, Pt. 5: Stratigraphic relations of the plant beds. *Meddl. Grønland*, Bd. 112, Nr. 2, 31-33.
- Jones, O. A. and de Jersey, N. J. (1947). The flora of the Ipswich Coal Measures. Morphology and floral succession. *Univ. Q'land Papers, Dept. Geol.*, 3, new series, Nos. 3, 4, 15-17.
- Schenk, A. (1867). Die fossile Flora der Grenzsichten der Keupers und Lias Frankens, 111, Wiesbaden.
- Seward, A. C. (1903). Fossil floras of Cape Colony. *Ann. S. Afr. Museum*, 4, 50-57.
- (1910). Fossil Plants, 2, 538. *Cambridge*.
- (1931). Plant life through the ages, 314-317. *Cambridge*.
- Thomas, H. H. (1933). On some Pteridospermous plants from the Mesozoic rocks of South Africa. *Phil. Trans. Roy. Soc. London*, Ser. B. 222, 193-265.
- Walkom, A. B. (1917). Mesozoic floras of Queensland. Pt. I: The flora of the Ipswich and Walloon Series. *Q'land. Geol. Surv.*, Publ. No. 257, 12-24.
- (1921). Mesozoic floras of New South Wales. Pt. I—Fossil plants from Cockabutta Mountain and Talbragar. *Mem. Geol. Surv. N.S.W.*, Pal., No. 12, 1-21.
- (1925). Fossil plants from the Narrabeen stage of the Hawksbury series. *Proc. Linn. Soc. N.S.W.*, 50, pt. 3, 214-224.
- (1928). Fossil plants from the Esk district, Queensland. *Proc. Linn. Soc. N.S.W.*, 53, pt. 4, 459-461.

A SIMPLE FORM OF VOLTAGE STABILIZER.

By N. K. SAHA, B. S. CHANDERSEKHARA and M. K. SUNDARESEN, *Physics Department, University of Delhi, Delhi.*

(Communicated by Dr. R. C. Majumdar, F.N.I.)

(Received December 22, 1949 ; read March 3, 1950.)

1. INTRODUCTION.

Usual forms of Geiger counters are generally operated at a voltage between 1000 and 2000 volts, and since their counting rate is a function of the applied voltage, this voltage should remain constant. Many vacuum tube circuits have been devised for this purpose. The main principle employed in some of these voltage stabilizers is that the variations in the output voltage, after rectification, bias the grids of a thermionic tube so as to maintain a constant plate current. Street and Johnson (1932) have devised two circuits using tetrodes, but they include batteries from which current is drawn and are therefore likely to lose their efficiency in long runs. Richards (1933) has given a circuit which eliminates batteries by substituting a separate full-wave rectifier, the control grids of the two triodes in the main rectifiers being biased by this auxiliary rectified voltage. But the apparatus is bulky, and the different time constants of thermal response of the filaments in the seven tubes in the circuit introduce large transients when the primary voltage is suddenly changed. Evans (1934) has described a stabilizer using only one battery from which current is not drawn. Gingrich (1936) has modified Evans' circuit, using a neon tube instead of the battery. He also describes a second circuit using a bank of neon tubes across which the stabilized voltage is obtained.

Neher and Pickering (1939) employ a different principle, where fluctuations of the input voltage vary the plate current in a pentode such that a constant output voltage is obtained, the excess voltage being dropped off across a series resistance. But two dry batteries are required. Banerjee (1942) has modified the Neher-Pickering circuit so as to use only one battery.

In all these circuits the point at which the voltage is stabilized is determined by varying one or more resistances. Most of them also require the use of one or more dry batteries. These are avoided in a stabilizer we have constructed, similar in principle to Gingrich's circuit using a bank of neon tubes, but eliminating the actual use of neon tubes.

2. DESCRIPTION AND WORKING.

In the present form of voltage stabilizer the property of gas ionization at reduced pressure is utilized. The circuit is shown in figure 1. T is the high tension transformer fed from the variac A . The output voltage is rectified by means of the tube $2X2$ and impressed on the 2-microfarad condenser C . A brass tube about a meter long and 12 millimeters in diameter with an axial insulated steel wire of 0.33 millimeter diameter constitutes the stabilizing tube, the two electrodes of which, the central wire and the body, are connected across the condenser plates in series with a high resistance R of about 30 megohms. The tube can be exhausted and filled with dry air at a desired pressure by means of a suitable system of stopcocks, drying tubes, manometer and vacuum pump.

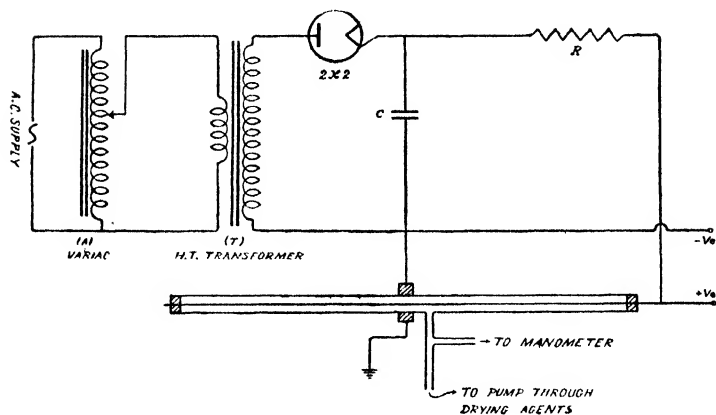


FIG. 1. The Experimental arrangement.

As the transformer output is increased from its lowest value (by means of the variac in its primary circuit), the voltage drop across the tube also increases. At a certain voltage characteristic of the pressure inside the tube, this voltage becomes constant, and remains so practically over a very large range of the transformer

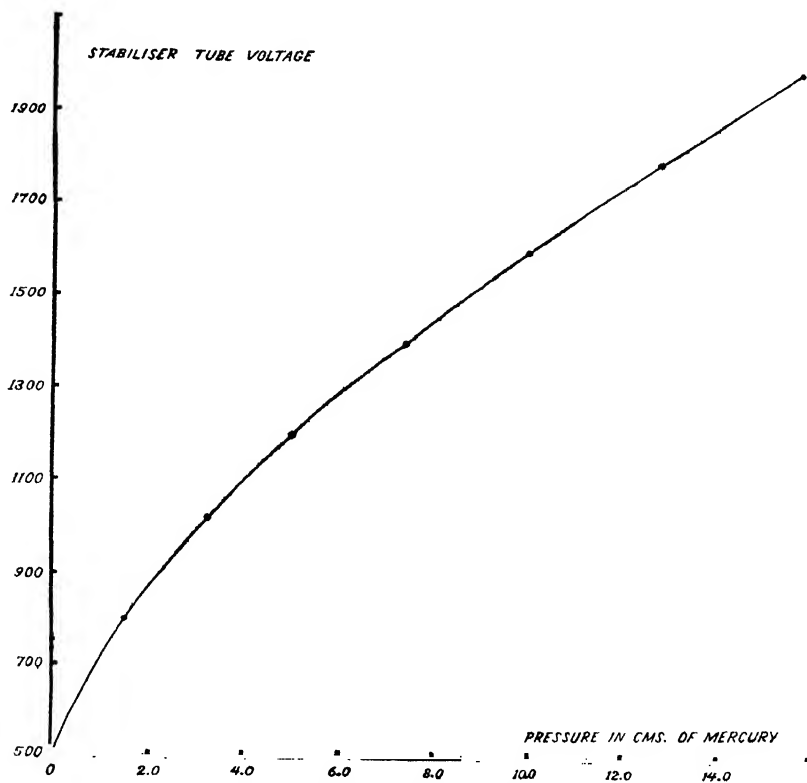


FIG. 2. The Pressure-Voltage Calibration Curve.

output voltage. This stabilized voltage depends entirely on the pressure in the tube and increases steadily with pressure, as shown in figure 2, which acts as the calibration curve for the stabilizer. The stabilization of the voltage at a given pressure is due to the fact that any increase in the transformer output causes a higher ionization current to flow in the tube; this leads to a higher potential drop across R which compensates the increase in the transformer output and the potential across the stabilizer tube remains constant.

3. CHARACTERISTICS.

The voltage across the stabilizer tube is shown as a function of the transformer output (rectified), for various fixed pressures inside the tube, in figures 3 *A, B, C* and *D*. At the region where stabilization just starts, spontaneous fluctuations of the tube voltage for a fixed transformer output are observed (as shown by the shaded areas in figures 3 *A, B, C, D*). These can be explained as follows: Let the transformer output voltage be equal to or slightly greater than the stabilized voltage. The stabilization just starts, the tube becomes suddenly conducting and this causes a large current to flow in the circuit. This in turn causes a large ohmic drop of potential across the series resistance R , and the available voltage across the tube instantaneously drops below the stabilized voltage. The gas ionization in the tube, however, tends to cease at the lower tube potential, resulting in a rapid fall in the current and a smaller potential drop across R . Eventually the original stabilized voltage across the tube is restored. The whole process appears as a current and voltage fluctuation with time in opposite senses somewhat like that shown in Fig. 4. The phenomenon can repeat itself several times. The fluctuations disappear when the transformer output is so large that, in spite of the voltage drop across R at the instant of striking of the ionization, the available voltage across the tube is equal to its striking voltage.

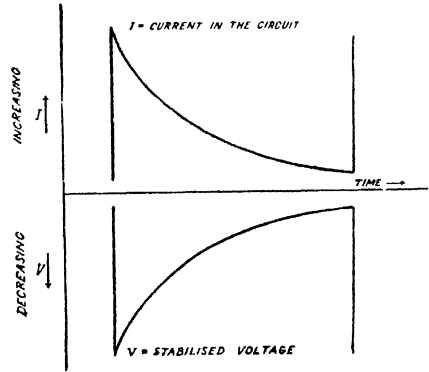


FIG. 4. Curve illustrating the initial current and voltage fluctuations at threshold.

The stabilization effect has also been tested for different values of the series resistance R . It is observed that a higher resistance ($R \approx 40$ megohms) gives a better stabilization than a lower resistance ($R \approx 10$ megohms). With the lower resistance, there is a slight increase in the stabilized voltage as the transformer output is increased steadily from the lower limit of stabilization up to the maximum output. The effect is more pronounced for high stabilized voltage. For example, when the transformer output is increased from about 2,000 to 3,500 volts (Fig. 3*A*), $R \approx 40$ megohms, the stabilized voltage at 8.6 cm. Hg pressure starts at 1,500 and increases steadily to 1,540, the increase being 40 volts over a range of 1,500 for the transformer output. With a series resistance of 10 megohms the stabilized voltage for the same pressure increases steadily from 1,500 to 1,580 over a range of the transformer output from 1,700 to 3,500 (Fig. 3*D*). Again as can be seen from the lowest curve of figure 3*A*, which is the voltage stabilization curve at the lowest attainable pressure at $R \approx 40$ megohms, the stabilized voltage is practically steady over a wide range of the transformer output. The second, third and fourth curves are respectively for the pressures 3.1, 8.6 and 15.6 centimeters of mercury. At these higher pressures, the stabilization naturally starts at gradually higher voltages (<1,000, 1,500 and 2,000), but the stabilized voltage also increases slightly by 20,

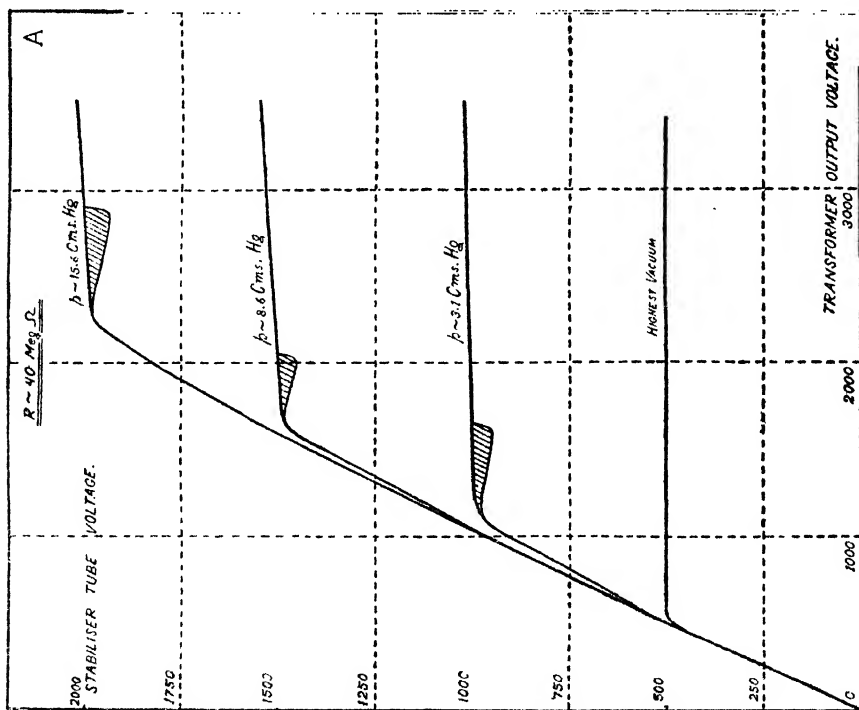
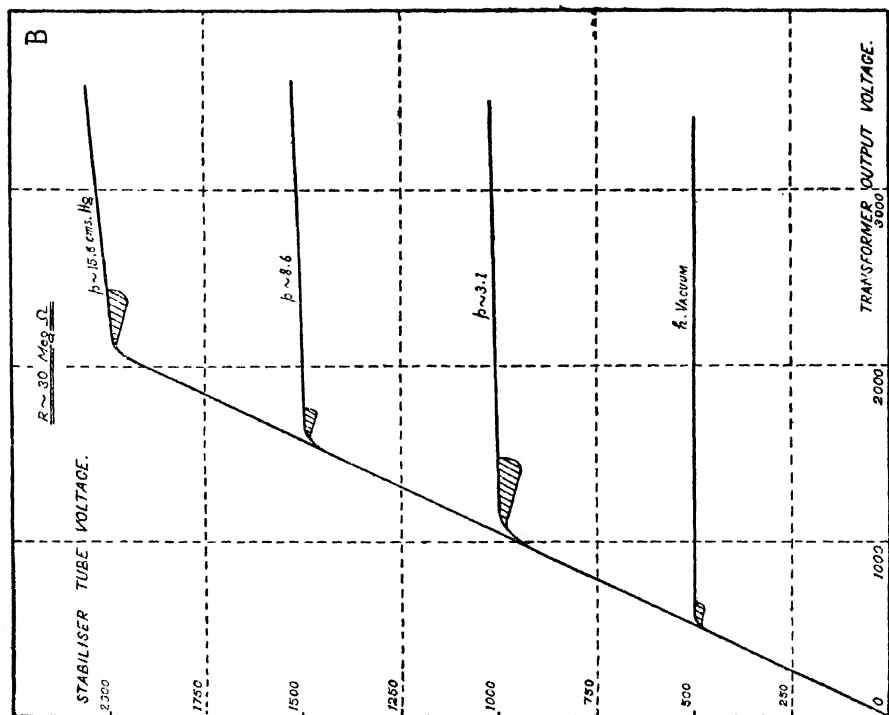


FIG. 3.

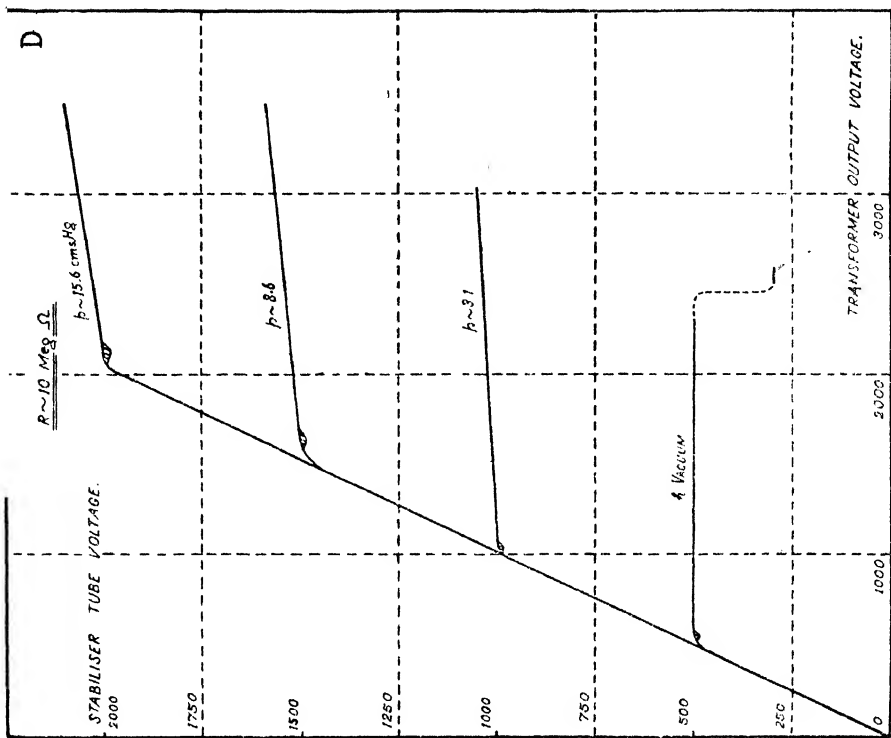
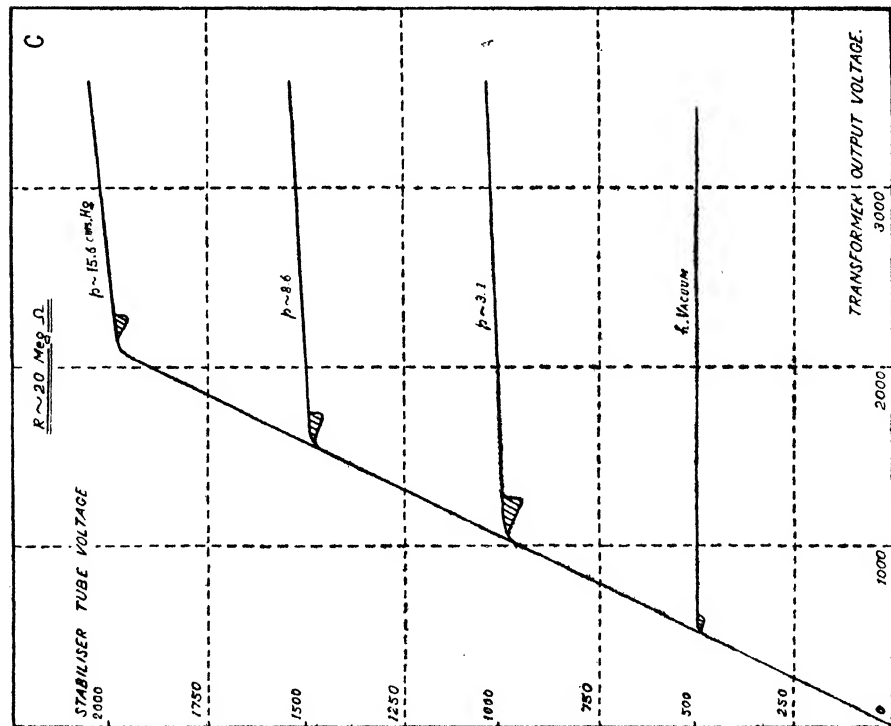


FIG. 3. A, B, C, D. The abscissa represents rectified transformer output voltage and the ordinate the voltage drop across the stabilizer tube. The stabilizer values of 500, 1,000, 1,500 and 2,000 volts are clearly seen to set in at full vacuum, the pressures of 3.1 cm., 8.6 cm. and 15.6 cm. mercury respectively. The Figs. A, B, C, D are for 40, 30, 20 and 10 megohms respectively as series resistance.

40 and ~ 20 (uncertain) volts respectively as the transformer output is varied steadily up to the maximum (3,500 volts).

It is to be understood that the success of the gas ionization tube as a voltage stabilizer is to be expected only when the current in the circuit remains within the linear part of the ionization current-voltage curve; the slight increase of the stabilized voltage observed under certain conditions as described above is due to the fact that the ionization current under these conditions has a less-than-linear increase with

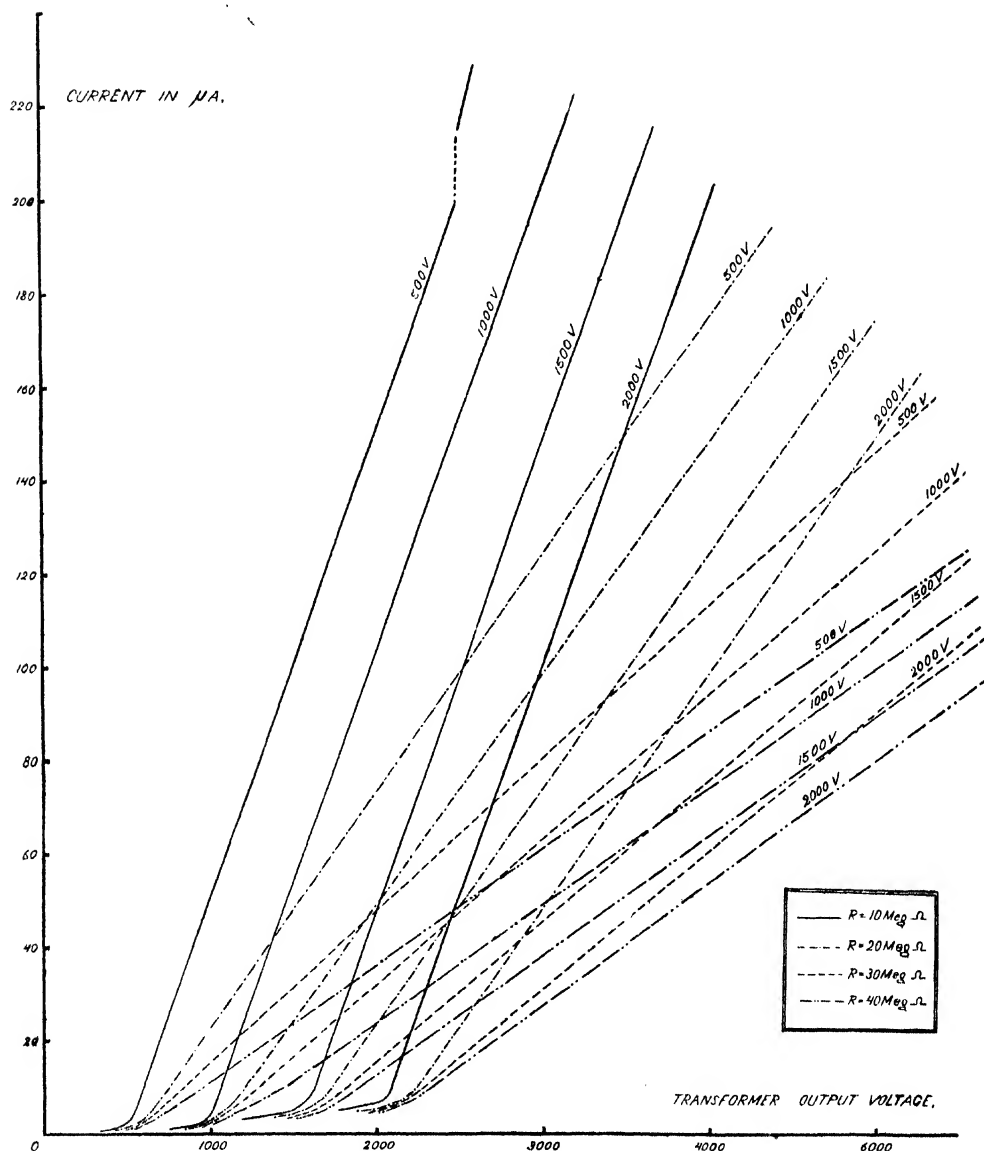


FIG. 5. The abscissa represents transformer output voltage after rectification, the ordinate the current through the stabilizer tube. The four sets of parallel curves are for the four series resistances 10, 20, 30 and 40 megohms. The four curves in each set are respectively for the stabilized voltages 500, 1,000, 1,500 and 2,000.

voltage. At a given series resistance the non-linearity increases with increasing pressure and at a given pressure the non-linearity increases with decreasing series resistance.

For a low series resistance ($R \sim 10$ megohms) and a low stabilized voltage (at the lowest attainable pressure) an interesting effect was observed. When the transformer output was increased beyond a limit there was a sudden drop in the stabilized voltage, which continued steady at this lower value for further increase of the transformer output. The effect is probably due to complicated gas ionization phenomena setting in at the high ionization current (~ 215 microamperes) flowing through the discharge tube.

Figure 5 shows the variation of the current in the stabilizer tube as a function of the D.C. input voltage from the transformer. For a given series resistance the current variation is shown for the four different stabilized voltages 500, 1,000, 1,500 and 2,000 V. forming a family of four curves with a nearly parallel run. Four such families of curves have been plotted for the series resistances 10, 20, 30 and 40 megohms. The stabilized voltage corresponding to any curve sets in just beyond the sharp kink in the curve, beyond which the curve is, in each case, sensibly linear, having a slope corresponding to the series resistance. The current in this region is therefore to be ascribed mainly to the corona discharge, since, on resolving the characteristic into two parts—one for the ohmic resistance R and the other for the stabilizer tube—the latter characteristic is nearly a straight line parallel to the current axis. The current in the pre-stabilization region is due to the primary ions present in the stabilizer tube produced by cosmic rays, stray radioactive radiation, etc., and also slightly due to the large ohmic resistance of the circuit.

For the series resistance $R = 10$ megohms and a stabilized voltage of 500, there is a discontinuity in the current characteristic at an input voltage of 2,500. This is simultaneous with the drop in the stabilizer voltage which has already been mentioned (see Fig. 3D, lowest curve) and is probably due to some kind of complex ionization of the gas setting in at a large current density.

The behaviour of the voltage stabilizer has been investigated up to the maximum transformer output of 3,500 volts available. The stabilization range of the curves in Fig. 3 probably extends to a higher voltage.

ABSTRACT.

A simple form of voltage stabilizer for the range 600–2,000 volts, suitable for use with G.M. counters, is described. The stabilization is effected with the help of gas-ionization in an air discharge tube of variable pressure connected in parallel to the transformer output. At a stabilized voltage of $\sim 1,500$ volts a deviation of $\sim 2.5\%$ was observed when the transformer output was varied between 2,000 and 3,500 volts. As such a wide variation in the transformer output is not likely to occur in practice, the stabilization attained is generally satisfactory. Simplicity of the electrical circuit, ease of operation in changing the range of stabilized voltage, good accuracy and low cost are the main features of the method.

REFERENCES.

- Banerjee (1942). Voltage Stabilizing Circuit. *Ind. J. Phys.*, **16**(II), 87.
 Evans, R. D. (1934). Voltage Stabilizer controlled by a thermoionic Pentode. *Rev. Sci. Inst.*, **5**, 371.
 Gingrich, N. S. (1936). Voltage sources and Amplifiers for Geiger Counters. *Ibid.*, **7**, 207.
 Neher, H. V. and Pickering, W. H. (1939). Two voltage Regulators. *Ibid.*, **10**, 53.
 Richards, L. A. (1933). The use of triode vacuum tube rectifiers to supply constant voltage. *Ibid.*, **4**, 479.
 Stroet, J. C. and Johnson, T. H. (1932). Use of Tetrode for voltage Control. *J. Franklin Inst.*, **214**, 155.

PHYSIOLOGICAL STUDIES ON THE EFFECT OF COLCHICINE ON RICE. II.

By B. N. GHOSH, *Department of Botany, Calcutta University.*

(Communicated by Dr. I. Banerji, F.N.I.)

(Received April 30; read August 5, 1949.)

INTRODUCTION.

In a previous paper of this series it has been reported by the author (Ghosh, 1948) that low concentrations of colchicine appear to act as a stimulant to rice plant producing more tillers and ears, and inducing early flowering with increased grain yield. As indicated previously the object of the author is to produce a stable polyploid rice plant by treating with colchicine since its action is known to be directly related to the doubling of chromosomes and presumably these increased numbers of chromosomes may be transmitted to succeeding generations. As a result, a stable polyploid rice plant may well be expected. Polyploid plants can be of much economic importance by increasing vegetative growth, size of spikelets, length of panicles and grain yield together with resistance to unfavourable environmental conditions. With this end in view progeny tests have been conducted from the 50 per cent. of seeds collected from the rice plants arising from colchicine treated seeds and seedlings without further treatment with colchicine in succeeding generations, while the other 50 per cent. of seeds have again been treated in succeeding generations with the same doses of colchicine as applied to parent seeds to see the cumulative effect if there be any. The descendants of the former group are called untreated progenies, and the descendants of the latter, treated progenies. The present paper deals with observations on vegetative growth, flowering and yield of these treated and untreated progenies.

EXPERIMENTAL PROCEDURE.

In the present investigation the same experimental technique was adopted as described earlier (Ghosh, 1948).

In 1942 seeds of *Dhairal* were treated with 1.0% and 0.05% colchicine for 48 hours, while the sprouted seeds were soaked in 0.05%, 0.1%, 0.5% and 1.0% colchicine for 2 hours; not a single seedling survived in 0.1% and 1.0% colchicine.

In 1943 the following procedure was adopted to compare the effects of colchicine treatment in the progenies of the treated and untreated rice plants. The seeds of the selected plants of 1942 were divided in two equal portions. Half of these were sown without further treatment with colchicine solution and the other half were again treated in the same manner as their parent seeds. The same procedure was repeated in 1944. Thus in one lot was examined the cumulative effect of colchicine treatment, if any, against the other which was not treated any further. Selection was made from the early flowering and high yielding plants. After treatment the seeds were thoroughly washed with water and transferred to moist blotting paper in petri-dishes for germination along with a control set. When the seedlings were sufficiently developed nine of them were taken from each treatment and sown in earthen pots (13" x 10") on 9th April in 1942, on 12th April in 1943 and on 1st and 2nd May in 1944 with 15, 6 and 6 replicates for each treatment respectively. After a week the pots were thinned, keeping only the best three plants in each pot.

The pots were filled with an equal quantity of garden soil which was dressed with 1/8th part by volume of cowdung manure; a handful of bone-meal was also added to each pot. The pots were watered with tap water. Data on tillering, plant height, size of stomata, ear emergence and grain yield were collected. The experiment was arranged in randomized blocks. The data for ear emergence, number and length of ears and grain yield were analysed statistically.

The outline of treatments given below illustrates the procedure:—

1942

A	..	Control.					
B	..	0.05% of colchicine solution; 48 hours' seed treatment.					
E	..	1.0% " " " "	48	"	"	"	"
J	..	0.5% " " " "	2	"	seedling treatment		
L	..	5% " " " "	2	"	"	"	"

1943

BP ₁	..	Progeny of B; untreated.		
EP ₁	..	" E; "		
JP ₁	..	" J; "		
LP ₁	..	" L; "		
BP ₁ B	..	" B; treated.		
EP ₁ E	..	" E; "		
JP ₁ J	..	" J; "		
LP ₁ L	..	" L; "		

1944

BP ₂	..	Progeny of BP ₁ ; untreated.		
BP ₁ BP ₁	..	" BP ₁ B "		
EP ₂	..	" EP ₁ E "		
EP ₁ EP ₁	..	" EP ₁ E "		
JP ₂	..	" JP ₁ J "		
JP ₁ JP ₁	..	" JP ₁ J "		
LP ₂	..	" LP ₁ L "		
BP ₁ BP ₁ B	..	" BP ₁ B treated.		
EP ₁ EP ₁ E	..	" EP ₁ E "		
JP ₁ JP ₁ J	..	" JP ₁ J "		

EXPERIMENTAL RESULTS.

Treatment of sprouted seeds.—Sprouted seeds when treated with colchicine for 2 hours show swelling of both radicle and plumule the extent of which varies with its concentration (Fig. 1).

Tillering.—The tillers were counted weekly from 6 to 12 weeks after sowing. The figures recorded in table 1 for tiller numbers include the main shoot.

In 1942 greater tiller number is seen in all the treated plants, the largest number being under 0.05% colchicine treatment; thus confirming previous observations (Ghosh, 1948). In L only two plants and in LP₁L of 1943 only one plant survived, so no stress is attributed to their number of tillers. In 1943 the largest number of tillers was observed in BP₁ and in 1944 in LP₁L.

In 1944 an interesting feature of tillering is observed. The maximum production of tillers is reached at early stages of growth, i.e., within 7th week after sowing, thereafter the number of tillers either remains constant or a reduction is observed due to the death of some tillers. So, a definite critical period of tillering is observed in treated and untreated progenies, while in control the tiller production is progressively increasing. A cumulative effect of colchicine treatment as evidenced by a distinct critical period of tillering is suggested.

In 1943 in LP₁L the whole plant became tetraploid as suggested by its gigas characters such as darker green colour of the leaves, remarkable increase in plant height and bigger size of the spikelets of all the ears which, however, failed to set

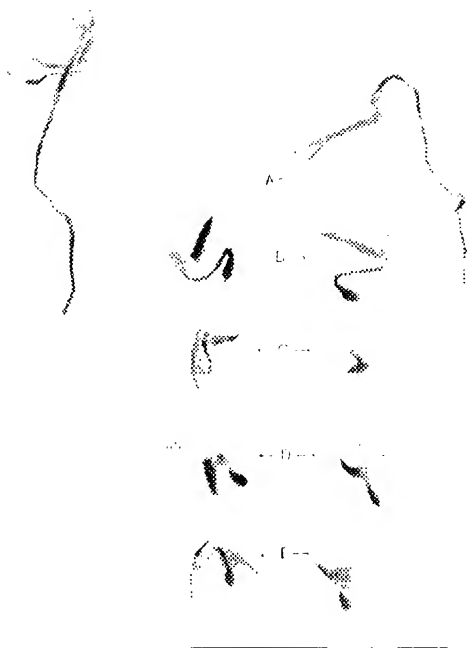


FIG. 1. Effect of varying doses of colchicine on sprouted rice seeds for 2 hours showing gradual swellings of both radicle and plumule.

A—Control; B—0.05%; C—0.1%; D—0.5%; E—1.0%.

grains. The plant also tillered very profusely. In 1944, in EP_1EP_1E bigger size of the grains of some of the tillers of some plants suggested that the tillers were tetraploids, the others remaining diploid. Most of the spikelets of the tetraploid tillers failed to develop grains.

Height.—Plant height was taken from the surface of the soil up to the tip of the top leaf of the main shoot. The data are given in table 2.

Marked prolongation to reach the maximum plant height was noticed in 1942 where the growth rate was very slow. In 1943, however, the growth rate of plant height of treated and untreated progenies including control was greater than the growth rate of the plants of 1942, while in 1944 the rate was further increased. This may be shown in the order: $1944 > 1943 > 1942$. The final height of the plants of the three years were more or less the same. Although the plants of 1944 took much shorter time to reach the final height, they were not weak and sickly and looked as healthy and vigorous as plants of 1942 and 1943 that had taken longer period to reach the final height.

In 1942, plants grown from colchicinetreated seeds and seedlings showed increased height over that of control; marked increase was found in B. In 1943, in all treated and untreated progenies plant height was greater than that of control; appreciable increase being noticed in EP_1E , JP_1J and LP_1 . In 1944, all the plants including control showed uniform growth of plant height; in EP_1EP_1E marked increase in height was noticed.

TABLE 1.
Average number of tillers per plant.

1942

Weeks after sowing.

Treatment.	VI	VII	VIII	IX	X	XI	XII
A ..	8.1	9.5	10.4	11.8	12.1	12.5	13.0
B ..	11.8	14.5	18.0	19.5	20.4	21.2	23.1
E ..	10.8	13.0	14.0	14.1	14.5	15.1	16.1
J ..	9.1	10.8	11.8	12.9	13.7	13.8	14.1
*L ..	3.6	4.1	6.5	9.5	11.5	12.5	13.0

1943

A ..	10.6	13.0	13.3	13.6	14.5	14.3	15.6
BP ₁ ..	11.2	14.8	14.9	15.4	16.1	16.2	16.5
BP ₁ B ..	11.0	13.9	13.8	14.4	14.6	14.8	15.2
EP ₁ ..	10.4	12.6	12.8	13.0	13.7	13.7	14.4
EP ₁ E ..	9.9	13.5	13.9	14.0	14.3	14.3	15.3
JP ₁ ..	10.3	12.8	13.0	12.9	13.3	13.3	14.2
JP ₁ J ..	9.3	12.8	13.9	14.4	15.2	15.5	15.7
LP ₁ ..	10.2	12.5	12.7	13.1	13.9	13.9	15.5
**LP ₁ L ..	13.0	20.0	20.0	20.0	20.0	20.0	21.0

1944

A ..	8.6	8.6	8.5	8.6	8.8	9.2	9.3
BP ₂ ..	8.6	8.7	8.7	8.7	8.7	8.7	8.7
BP ₁ BP ₁ ..	9.2	9.2	9.2	9.1	9.2	9.1	9.1
BP ₁ BP ₁ B ..	9.2	9.5	9.4	9.4	9.3	9.2	9.2
EP ₂ ..	9.1	9.1	9.0	9.1	9.0	9.0	8.9
EP ₁ EP ₁ ..	9.8	9.8	9.7	9.8	9.7	9.7	9.7
EP ₁ EP ₁ E ..	9.0	9.6	9.6	9.7	9.5	9.4	9.6
JP ₂ ..	9.2	9.2	9.2	9.2	9.2	9.1	9.1
JP ₁ JP ₁ ..	9.9	9.9	9.9	10.0	10.0	10.0	10.0
JP ₁ JP ₁ J ..	7.5	7.6	7.6	7.6	7.6	7.6	7.6
LP ₂ ..	8.1	8.3	8.2	8.1	8.1	7.9	7.9
LP ₁ L ..	10.0	10.2	10.1	11.8	11.9	12.2	12.2

* Surviving plants were only two.

** Surviving plant was only one.

Size of Stomata and of Pollen Grains.—Since polyploid individuals are characterized by increased size of stomata and pollen grains, preliminary observation for detection of the induced polyploidy in rice by colchicine treatment was made by examining the size of stomata and pollen grains.

The matured leaves of same stage of development were sampled for stomatal measurement at 8 A.M. on bright days from the control as well as from the treated and untreated progenies of 1943 and 1944. The epidermis of the leaf was stripped off with a fine scalpel and then plunged immediately into absolute alcohol for preservation in a permanent form without any change in the dimensions of the stomata. The measurements of stomata were recorded after staining them suitably with Bismarck brown. No increase in the size of stomata due to treatment was observed; they were to some extent smaller than those of control. The data are given in table 3.

The larger size of pollen grains was observed in treated progenies, while in untreated progenies the size was almost the same as the control.

TABLE 2.

Average plant height in cm.

1942

Weeks after sowing.

Treatment.	VI	VII	VIII	IX	X	XI	XII
A ..	32.0	39.4	44.9	49.5	55.2	58.7	62.0
B ..	34.6	42.1	47.3	52.0	60.5	63.6	68.3
E ..	33.8	40.9	46.8	50.6	56.7	60.8	65.4
J ..	32.4	39.8	44.3	48.4	56.2	59.7	63.2
*L ..	23.6	30.3	40.3	45.1	49.4	50.7	60.9

1943

A ..	42.3	48.9	67.2	77.3	84.6	88.8	92.3
BP ₁ ..	43.1	51.4	66.4	75.8	82.6	88.1	95.8
BP ₁ B ..	42.5	49.7	66.5	77.3	84.4	89.2	94.9
EP ₁ ..	43.4	52.0	69.9	80.5	88.2	94.3	99.6
EP ₁ E ..	46.0	56.2	73.0	83.2	92.7	99.4	110.2
JP ₁ ..	44.3	52.0	69.6	77.7	88.1	93.6	101.0
JP ₁ J ..	44.5	50.3	67.2	79.9	87.0	93.6	97.2
LP ₁ ..	45.9	52.6	69.3	77.9	87.2	94.2	99.2
**LP ₁ L ..	55.8	61.0	78.5	96.6	101.5	106.5	113.2

1944

A ..	50.7	59.9	66.2	72.2	80.2	88.8	92.1
BP ₂ ..	52.8	63.1	68.3	72.9	80.2	87.4	91.8
BP ₁ BP ₁ ..	50.5	59.6	64.3	68.7	74.5	83.4	88.6
BP ₁ BP ₁ B ..	51.9	60.3	67.7	73.8	82.1	90.2	92.9
EP ₂ ..	48.2	57.5	64.8	70.5	78.3	89.3	93.2
EP ₁ EP ₁ ..	52.9	61.9	68.0	73.4	79.9	88.2	91.7
EP ₁ EP ₁ E ..	56.6	63.3	70.1	76.6	82.1	92.2	100.1
JP ₂ ..	48.4	56.9	63.0	68.0	72.7	81.1	85.9
JP ₁ JP ₁ ..	54.9	63.7	70.1	76.1	86.4	94.8	96.7
JP ₁ JP ₁ J ..	49.4	57.5	63.8	67.7	71.3	79.0	85.6
LP ₂ ..	49.6	58.8	66.3	71.1	78.3	88.3	91.9
LP ₁ L ..	52.7	60.8	66.4	72.4	79.2	87.1	91.9

* Surviving plants were only two.

** Surviving plant was only one.

Ear emergence.—In 1942, ear emergence occurred in both the control and plants from colchicine treated seeds and seedlings between the period middle of July to the first week of August and, in 1943, during the first half of July. While in 1944 with a late sowing by 18 days the flowering range of all plants was the same as in 1943. Thus the flowering duration (sowing to flowering) in three consecutive years varied between 96–106 days in 1942, 78–88 days in 1943 and 67–74 days in 1944. The data are given in Table 4. From statistical analysis of three years' data of ear emergence it is found that colchicine treatment induces no significant earliness in flowering, but significant retardation in flowering at 5% level from control by repeated doses of 1% and .05% colchicine on seed and seedling progenies (EP₁EP₁E and JP₁JP₁J) respectively is noticed in 1944 (Table 5). A marked difference in earing time as noticed in three successive years appears to have been due to the use of selected seeds from early flowering plants of both control and treated and untreated progenies.

TABLE 3.

Measurement of the size of stomata (average of 75 observations).

1943

Treatment.	Length.	Breadth.
A ..	31.399 μ	21.109 μ
BP ₁ ..	27.224 "	18.992 "
EP ₁ E ..	26.989 "	20.227 "
LP ₁ L ..	28.283 "	20.756 "

1944

A ..	31.046 "	19.522 "
BP ₁ BP ₁ ..	25.225 "	16.993 "
BP ₁ BP ₁ B ..	26.636 "	17.464 "
EP ₁ EP ₁ ..	26.284 "	17.640 "
EP ₁ EP ₁ E ..	28.812 "	18.522 "
JP ₁ JP ₁ ..	26.342 "	17.816 "
JP ₁ JP ₁ J ..	27.695 "	17.816 "
LP ₂ ..	27.107 "	17.287 "
LP ₁ L ..	29.165 "	17.816 "

Number and length of ears.—The total number of ears per plant was counted at harvest. The data are given in Table 4.

In 1942, maximum number of ears was found in B, thus confirming the previous work (Ghosh, 1948). In higher concentrations and in seedling treatment the number decreased from that of the control. This result is statistically significant at 1% level (Table 6). The differences in the number of ears per plant between the control and the treated and untreated progenies of both 1943 and 1944 do not appear statistically significant. This indicates that the ear number of the progenies of both 1943 and 1944 remains unaffected by further doses of colchicine in successive generations. As for the number of ears in the three successive years it was found that in 1943 ear number was greater than in 1942, while in 1944 the number was less than in 1943. This variation in ear number of both control and treated and untreated progenies in three successive years is possibly due to the environmental conditions which vary from year to year.

The percentage of ear-bearing tillers of both treated and untreated progenies was found to increase in successive years, except in EP₁EP₁E and EP₁EP₁ (the treated and untreated progenies of EP₁E of 1943) where percentage of ear-bearing tillers was found less than in EP₁E of 1943. In 1942, greater number of tillers were found sterile. In 1943, the number of sterile tillers decreased, while in 1944 almost all the tillers bore ear-heads, the percentage of ear-bearing tillers being greater than in the control. This indicates that in 1944, almost all the tillers of both treated and untreated progenies bore ear-heads and a large number of tillers of the control plants did not bear ears or died immature.

From statistical analysis of the data of ear length (Table 7) it appears that the repeated treatment with 1% and .5% colchicine in 1944 on seed and seedling progenies (EP₁EP₁E and LP₁L) showed a significant increase at 1% level over the control, while in 1943, the differences between control plants and treated and untreated progenies were not statistically significant. This shows a cumulative effect of colchicine on ear length in 1944.

TABLE 4.

Showing number of days for ear emergence, number and length of ears, grain yield and ears as P.C. of maximum number of tillers.

1942

Treatment.	Number of days from sowing to flowering.	Number of ears.	Length of ears in cm.	Grain yield per plant in grm.	Ears as P.C. of maximum number of tillers.
A	105.9	4.2	..	2.4	30.4
B	99.7	8.2	..	5.0	33.4
E	103.5	4.0	..	2.6	23.5
J	101.2	3.6	..	2.3	24.3
*L	96.5	9.0	..	10.8	69.2

1943

A	..	..	85.4	8.6	20.5	7.7	57.6
BP ₁	..	..	82.4	10.5	19.5	16.2	69.6
BP ₁ B	..	..	82.8	9.2	20.4	10.5	60.5
EP ₁	..	..	82.1	10.4	20.9	12.3	72.2
EP ₁ E	..	..	79.1	15.0	22.6	28.6	82.3
JP ₁	..	..	80.3	10.8	21.1	15.7	76.0
JP ₁ J	..	..	84.8	10.3	21.5	11.9	56.0
LP ₁	..	..	82.3	9.6	21.5	10.5	61.9
**LP ₁ L	..	..	78.0	21.0	24.0	Sterile	100.0

1944

A	..	..	69.1	6.2	16.4	6.68	66.7
BP ₂	..	..	71.5	6.7	16.8	6.04	77.0
BP ₁ BP ₁	..	..	70.7	6.7	15.3	5.31	72.8
BP ₁ BP ₁ B	..	..	68.7	7.0	16.5	6.77	73.6
EP ₂	..	..	69.6	6.7	16.0	5.85	73.6
EP ₁ EP ₁	..	..	70.7	6.8	16.4	5.81	69.3
EP ₁ EP ₁ E	..	..	73.3	6.8	19.6	9.96	67.0
JP ₂	..	..	71.6	7.1	14.5	5.76	78.2
JP ₁ JP ₁	..	..	67.2	7.2	17.1	7.82	72.0
JP ₁ JP ₁ J	..	..	74.1	5.7	15.3	4.82	75.0
LP ₂	..	..	70.2	6.4	17.0	6.11	69.8
LP ₁ L	..	..	72.8	9.8	18.3	10.85	69.6

*Surviving plants were only two.

** Surviving plant was only one.

TABLE 5.

Analysis of variance of the data of the ear emergence, 1944.

Source of variation.	Degrees of freedom.	Mean square.	Ratio.
Between treatments	.. 11	23.7245	2.3221
Within treatments	.. 60	10.2141	

[illegible]¹ Significant at 5% level.

TABLE 6.

Analysis of variance of the data of the number of ears, 1942.

Source of variation.	Degrees of freedom.	Mean Square.	Ratio.
Between treatments	3	58.3766	11.565 ¹
Within treatments	50	5.0474	

Conclusion: B > Cont., E, J.

TABLE 7.

Analysis of variance of the data of ear length, 1944.

Source of variation.	Degrees of freedom.	Mean Square.	Ratio.
Between treatments	11	11.2927	4.897 ¹
Within treatments	60	2.3056	

Conclu- sion	EP ₁ EP ₁ E, LP ₁ L, JP ₁ JP ₁ , LP ₂ , BP ₂ , BP ₁ BP ₁ B, EP ₁ EP ₁ , Cont., EP ₂ , JP ₁ JP ₁ J, BP ₁ BP ₁ , JP ₂ .

¹ Significant at 1% level.

Grain Yield.—In 1942, maximum grain yield was found in B which is statistically significant at 1% level. In 1943 grain yield of all the treated and untreated progenies increased over that of the control; an improvement at 5% level of significance being in EP₁E. In 1944, treated progenies (EP₁EP₁E and LP₁L) showed significant increase at 1% level in grain yield over the control, while the other treated progenies and also the untreated progenies showed no significant difference in grain yield from that of the control (Table 8). As has been noted before that some of the tillers of EP₁EP₁E produced considerably bigger grains (Fig. 2), indicating that these tillers became tetraploids, the others remaining diploids. The individual weight of the bigger grains of the tetraploid tillers and that of the normal grains of the diploid tillers were found to be 31.00 mg. and 25.80 mg. respectively. It is interesting to note that the single grain weight of both tetraploid and diploid tillers of EP₁EP₁E was greater than that of the control plants; the single grain weight of the control plants was 24.20 mg. In all treated and untreated progenies of 1944 the number of sterile grains per plant increased over that of the control; marked increase of 145.6 and 69.8 per cent. in grain sterility over the control was found in LP₁L and EP₁EP₁E respectively, thus indicating that to some extent treatment with colchicine leads to sterility.

On the tetraploid tillers of EP₁EP₁E tiny little awn was found to develop only on two apical spikelets, all the other panicles remaining awnless. The awned spikelets were not developed into grains. In EP₁EP₁E one sheathed ear was noticed but the grains of it failed to set.

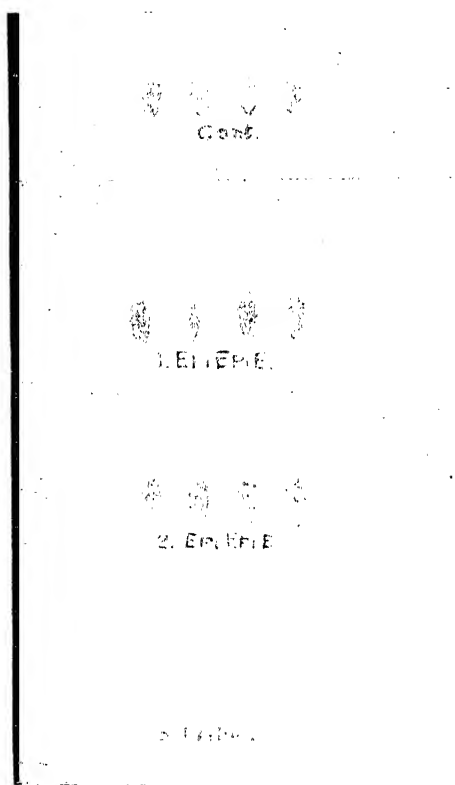


FIG. 2. Showing grains of rice from the control, and from the tetraploid chimera. Note bigger size of grains in latter.

DISCUSSION.

The tillering data presented in this paper (table 1) show clearly that in 1942 and 1943, the number of tillers increased with time in both control and treated plants. In 1944, the maximum number of tillers was produced within 7 weeks after sowing in treated and untreated progenies and thereafter the number of tillers either remained constant or decreased, whereas in control the number continued to increase up to 12 weeks. So, a cumulative effect has been obtained by colchicine treatment as evidenced by a distinct critical period of tillering in treated and untreated progenies of 1944. Engledow (1923, 1924 and 1926) in his wheat experiment stresses the importance of early tiller formation as an index of high yielding capacity in a variety. Grant and Thein Aung (1941) have observed no definite critical period of tillering in rice under lower Burma conditions, while Ramiah and Narasimhan (1936) obtained a definite critical period of tillering in rice.

A clean tetraploid plant was obtained in LP_1L in 1943 but the plant failed to set grains. In 1944, in EP_1EP_1E diploid and tetraploid chimeras having longer ears and bigger grains were obtained. It is expected that in subsequent generation a clean tetraploid might arise from these bigger grains. Blakeslee (1939) observed in *Datura stramonium* grown from a seed treated with colchicine both $2n$ and $4n$ branches, and an explanation has been given by Bergner *et al.* (1940) that when seeds

TABLE 8.

Statistical analysis of grain yield data.

1. Analysis of variance of grain yield data, 1942;

Source of variation.	Degrees of freedom.	Mean Square.	Ratio.
Between treatments	.. 3	21.1626	6.418 ¹
Within treatments	.. 50	3.2972	

Conclusion: B > E, Cont., J.

2. Analysis of variance of grain yield data, 1943:

Between treatments	.. 7	219.6934	2.886 ²
Within treatments	.. 38	76.1034	

Conclusion: EP₁E > BP₁, JP₁, EP₁, JP₁J, BP₁B, LP₁, Cont.

3. Analysis of variance of grain yield data, 1944 :

Between treatments	.. 11	20.5033	2.712 ¹
Within treatments	.. 60	7.5579	

Conclu- LP₁L, EP₁EP₁E, JP₁JP₁, BP₁BP₁B, Cont., LP₂, BP₂, EP₂, EP₁EP₁, JP₂, BP₁BP₁, JP₁JP₁J.
sion. [] []¹ Significant at 1% level.² Significant at 5% level.

are soaked in colchicine solutions for varying lengths of time different cells in the epicotyl may be affected differently. Consequently the plant that develops may be a chimera of one sort or another.

There was little effect of the colchicine treatment on stomatal size and if at all any it tended to reduce it. The size of the pollen grains was larger in treated progenies. Sears (1939) has also observed no changes in the size of stomata as well as in external structures of the induced polyploid material of wheat crosses. Blake-slee (1939) states that larger size of stomata is characteristic of tetraploids but this holds strictly only for comparable leaves. Stomatal size was found a reliable criterion when the stomata were taken from the floral bracts of females. The induced polyploidy can be detected more accurately by the measurement of pollen grains than of stomata (Dermen, 1940). But the surest way of detecting polyploidy is the actual counting of chromosomes.

In 1942, significant increase in grain yield over the control was noticed in B, thus confirming the previous observations of the author (Ghosh, 1948). In 1943, marked increase in yield was observed in EP₁E, and in 1944, in EP₁EP₁E and LP₁L. Colchicine appeared to retard ear emergence particularly in treatments EP₁EP₁E and JP₁JP₁J (Table 5), thus contradicting the observations reported previously (Ghosh, 1948). Awn was found to develop on two apical spikelets of the tetraploid tillers of EP₁EP₁E and one sheathed ear was also noticed in the same treatment. The occurrence of sheathed ear and awn on apical spikelets was caused by the cumulative effect of colchicine which was discussed in an earlier paper (Hedayetullah and Ghosh, 1946). Some of the tillers of EP₁EP₁E produced bigger grains suggesting that they were tetraploids and their single grain weight was found 28.1 per cent. greater than that of the control. Tetraploid plants may be expected from these bigger grains. Chen Shao-lin and Tang (1945) have reported that

colchicine-induced auto-tetraploid barley seedlings are better resistant to drying than the normal diploids. Müntzing (1936) states that polyploids are more resistant and more adaptable to adverse environmental conditions than the diploids. Whether the tetraploid plants from bigger grains of EP_1EP_1E will prove to be of economic value still remains to be seen.

ACKNOWLEDGEMENTS.

In conclusion, the authour expresses his sincere thanks to Dr. S. Hedayetullah for granting facilities to conduct this experiment at the Central Agricultural Research Station, Dacca, and to Dr. S. M. Sircar for reading the manuscript.

SUMMARY.

Sprouted and unsprouted seeds of *Dhairal*, summer (*aus*) paddy, and their progenies in three generations (1942, 1943 and 1944) were treated with different concentrations of colchicine for various lengths of time.

The sprouted seeds when treated with colchicine showed swelling of both radicle and plumule, whereas in unsprouted seeds only plumule swelled. The swelling of radicle and plumule increased with increase of colchicine concentration.

A definite critical period of tillering up to 7th week of sowing was found in both the treated and untreated progenies of 1944, while in the control the tiller number continued to increase till the 12th week after sowing. In 1942 and 1943, no such critical period of tillering was observed.

In 1943, a clean tetraploid plant was obtained from sprouted seed when treated with 0.5 per cent. colchicine for two consecutive generations, but the grains of it did not set in. In 1944 tetraploid tillers with bigger grains than those of the control were noticed in some plants grown from seed treated repeatedly for three generations with 1.0 per cent. colchicine for 48 hours. The single grain weight of the bigger grains was found to be 28.1 per cent. greater than that of the control. Whether the plants grown from the bigger grains prove to be of economic importance remains yet to be seen.

There was no increase in the size of the stomata in different treatments of the treated and untreated progenies, while the pollen-grain size was found to have increased in the treated progenies only.

Colchicine seemed to have no effect on the acceleration of ear emergence; on the contrary, in 1944, significant retardation in flowering due to cumulative effect of colchicine was noticed in plants grown from seeds and seedlings treated for three successive generations with 1.0 per cent. and 0.5 per cent. colchicine for 48 and 2 hours respectively.

As regards grain yield, the untreated progenies showed no significant improvement, while treated progenies gave increased yield over the control. In 1942, yield increased in 0.5 per cent. colchicine treatment. In 1943 and 1944 progenies treated successively for two and three generations with 1.0 per cent. colchicine for 48 hours showed significant increase over the control. In 1944, an increase was also noticed in plants from sprouted seeds treated for two successive generations with 0.5 per cent. colchicine for two hours.

REFERENCES.

- Bergner, A. D., Avery, A. G. and Blakeslee, A. F. (1940). Chromosomal deficiencies in *Datura stramonium* induced by colchicine treatment. *Amer. Jour. Bot.*, **27**, 676-683.
- Blakeslee, A. F. (1939). The present and potential service of chemistry to plant breeding. *Amer. Jour. Bot.*, **26**, 163-172.
- Chen, Shao-lin, and Tang, P. S. (1945). Studies on colchicine induced autotetraploid barley. III. Physiological studies. *Amer. Jour. Bot.*, **32**, 177-179.
- Dermen, H. (1940). Colchicine polyploidy and Technique. *Bot. Rev.*, **6**, 599-635.
- Engledow, F. L. (1923). Investigations on yield in the cereals. I. *Jour. Agri. Sci., Cambridge*, **13**, 390.
- and Wadham, S. M. (1924). Investigations on yield in the cereals. I. *Ibid.*, **14**, 66.
- Engledow, F. L. (1926). A census of an acre of corn. *Ibid.*, **16**, 166.
- Ghosh, B. N. (1948). Physiological studies on the effect of colchicine on rice (Preliminary report). *Jour. Ind. Bot. Soc.*, **27**, 119-130.
- Grant, J. W. and Thein Aung, U. (1941). Growth studies in rice. *Ind. Jour. Agri. Sci.*, **11**, 580-588.
- Hedayetullah, S. and Ghosh, B. N. (1946). The effect of colchicine on rice. *Curr. Sci.*, **15**, 74-75.
- Müntzing, A. (1936). The evolutionary significance of autopolyploidy. *Hereditas*, **21**, 263-378.
- Ramiah, K. and Narasimhan, M. (1936). Developmental studies in rice. *Mad. Agri. Jour.*, **24**, 50.
- Sears, E. R. (1939). Amphidiploids in the Triticinae induced by colchicine. *Jour. Hered.*, **30**, 38-43.

ON A NEW TYPE OF PARTITION.

By F. C. AULUCK, K. S. SINGWI, and B. K. AGARWALA,
University of Delhi, Delhi.

(Received April 15 ; read May 5, 1950.)

ABSTRACT.

The present paper is concerned with an investigation of a new type of partitions in which the total number of summands is unrestricted but the number of different summands that can occur is only N . The problem is treated analytically and asymptotic formulae have been derived in the two limiting cases: (i) when N is very large and (ii) when it is small. The case when N is unrestricted is also dealt with.

1. Introduction.

An interesting application (Auluck, Kothari, Agarwala, 1946-47) of the methods of statistical thermodynamics has recently been made to the problem of the partitions of numbers. A thermodynamic investigation of the partition theory suggests new types of problems and draws attention to various generalizations of the partition concept. The problem of partitions corresponds physically to an evaluation of the number of states accessible to a thermodynamic assembly suitable for a particular partition function. If, for example, the problem be to evaluate the partitions of an integer n into smaller positive integers, no restriction being placed on either the number of summands or the repetition of any summand, the suitable thermodynamic assembly is one of linear Bose-Einstein oscillators in which the individual energy levels are equidistant and given by $\epsilon_i = i\Delta$ where $i = 1, 2, 3, \dots$ and Δ is the spacing of the levels. The required partitions of n then correspond to an evaluation of the accessible states of this assembly when in the energy state $E = n\Delta$. This number, as is well known, is given by the coefficient of x^n in the development

$$Z = \prod_{i=1}^{\infty} (1 + x^i + x^{2i} + x^{3i} + \dots),$$

where $x = e^{-\Delta/kT}$.

By a suitable modification of this assembly one can impose restrictions on the number and nature of the summands. Thus if in the above example we require partitions into a fixed number k of summands the number of oscillators in the assembly must be restricted to k and the partitions are then enumerated by the coefficient of $x^n \zeta^k$ in the expansion

$$Z = \prod_{i=1}^{\infty} (1 + \zeta x^i + \zeta^2 x^{2i} + \zeta^3 x^{3i} + \dots).$$

If in addition to integers we also require half odd integers to occur in the partitions of n and allow any summand to repeat only an odd number of times the state-function of the corresponding thermodynamic assembly will be given by

$$Z = \prod_{i=1}^{\infty} (1 + \zeta x^{1/2} + \zeta^3 x^{3/2} + \zeta^5 x^{5/2} + \dots), \quad \dots \quad (1)$$

and the partitions into a fixed number of summands k will again be enumerated by the coefficient of $\zeta^k x^n$ in the above expansion. What restricts the total number of summands is obviously the power of ζ .

An interesting problem arises when we consider the generating function *

$$Z = \prod_{i=1}^{\infty} (1 + \zeta x^{\frac{1}{2}i} + \zeta x^{\frac{3}{2}i} + \zeta x^{\frac{5}{2}i} + \dots). \quad \dots \quad (2)$$

Since the powers of x in (2) are the same as in (1) the generating function (2) will still enumerate partitions into integers and half odd integers repeated only an odd number of times with one important difference that while the power k of ζ occurring in (1) restricts the total number of summands to a fixed number k this power in (2) restricts not the total number of summands but the number of different † summands that can occur. Such partitions, we believe, have not been considered before and it is, therefore, of interest to investigate the problem in detail.

In section 2 we give a general expression for the number of accessible states of the Born-Peng assembly. In section 3 we evaluate the partitions of n in the above specified manner when the number N of the types of summands that can occur in large and in section 4 the partitions are evaluated for small N . These are the two limiting cases. In section 5 we solve the same problem for $\zeta = 1$ which removes the restriction on the types and, therefore, enumerates the partitions of n into integers and half odd integers repeated only an odd number of times.

2. The density $\rho(E, N)$ of energy levels.

In the customary theory of Born and Peng the energy levels ϵ_i of the 'radiation' oscillators are assumed to be half odd integral and capable of accommodating 1, 2, 3, ... quanta. For purposes of interpretation in the partition theory we shall assume that in the states-function (2), which when written out in detail is

$$\begin{aligned} & (1 + \zeta x^{\frac{1}{2}} + \zeta x^{\frac{1}{2}+1+\frac{1}{2}} + \zeta x^{\frac{1}{2}+1+\frac{1}{2}+1+\frac{1}{2}} + \dots) \\ & (1 + \zeta x^1 + \zeta x^{1+1+1} + \zeta x^{1+1+1+1+1} + \dots) \\ & (1 + \zeta x^{\frac{3}{2}} + \zeta x^{\frac{3}{2}+\frac{3}{2}+\frac{3}{2}} + \zeta x^{\frac{3}{2}+\frac{3}{2}+\frac{3}{2}+\frac{3}{2}+\frac{3}{2}} + \dots), \\ & \dots \dots \dots \end{aligned}$$

the energy levels are $\frac{1}{2}$, 1, $\frac{3}{2}$, 2 ... and each of these levels can admit only an odd number of quanta, i.e., we assume

$$\epsilon_i = i\Delta \quad (i = 1, 2, 3, \dots) \quad \text{and} \quad \Delta = \frac{1}{2}.$$

To evaluate the required partitions of n we have then to evaluate the coefficient of $\zeta^N x^n$ in the expansion (2). This is the same as evaluating first the coefficient of $\zeta^N x^E$ ($E = n\Delta$) in the development

$$\prod_{i=1, 2, 3, \dots} (1 + \zeta x^{\frac{1}{2}\epsilon_i} + \zeta x^{\frac{3}{2}\epsilon_i} + \zeta x^{\frac{5}{2}\epsilon_i} + \dots), \quad \dots \quad (3)$$

* This function arises in the recent theory (Schrodinger, 1946) of Born and Peng in which these authors in an attempt to get rid of the infinite self-energy of the radiation field attribute to any one of the 'hohlraum' oscillators two fundamentally different situations. It can either be not excited at all when it has the energy zero or excited when it has one of the energies $\frac{1}{2} h\nu_s$, $\frac{3}{2} h\nu_s$, $\frac{5}{2} h\nu_s$, ..., where ν_s is the frequency of the s th oscillator. It is further assumed that the number of excited oscillators is only N . The 'Zustände' of such an assembly is given by (2).

† Consider, for instance, the number 8 partitioned in the following manner:—

$$8 = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + 1 + 1 + 1 + \frac{3}{2} + 2.$$

In the generating function (1) the above partitions of (8) would correspond to the coefficient of ζ^8 while in (2) where the types of summands are restricted and not the total number, these partitions will correspond to the coefficient of ζ^4 .

and then putting $\frac{E}{\Delta} = n$. The coefficient of $\zeta^N x^E$ in (3) is given by

$$\begin{aligned} \rho(E, N) &= \frac{1}{(2\pi i)^2} \oint \oint_{\epsilon_i} \frac{\prod \left\{ 1 + \frac{\zeta}{x^{-\frac{1}{2}\epsilon_i} - x^{\frac{1}{2}\epsilon_i}} \right\}}{\zeta^{N+1} x^{E+1}} dx d\zeta \\ &= \frac{1}{(2\pi i)^2} \oint \oint \frac{d\zeta}{\zeta} \frac{dx}{x} \Phi(\zeta, x), \quad \dots \dots \dots (4) \end{aligned}$$

where the integrals are taken over closed contours round the origins of the complex ζ and x planes and

$$\begin{aligned} \Phi(\zeta, x) &= \frac{e^{f(\zeta, x)}}{\zeta^N x^E}, \\ \text{with } f(\zeta, x) &= \sum_{\epsilon_i} \log \left\{ 1 + \frac{\zeta}{x^{-\frac{1}{2}\epsilon_i} - x^{\frac{1}{2}\epsilon_i}} \right\}. \end{aligned} \quad \dots \dots (5)$$

The integrand has along the real x and ζ axes sharp minima at $\zeta = a$ and $x = b$ where a and b are given by

$$a \frac{\partial f}{\partial a} = N, \quad b \frac{\partial f}{\partial b} = E. \quad \dots \dots (6)$$

By letting the paths of integration pass through these points one can apply the usual method of steepest descents for the evaluation of (4). The result (Lier and Uhlenbuk, 1937) is

$$\rho(E, N) = \frac{1}{2\pi \sqrt{k_0 k_2 - k_1^2}} \exp \{ \alpha N + 2\beta E + f(a, b) \}, \quad \dots \dots (7)$$

where

$$\begin{aligned} a^{-1} &= e^\alpha, \\ b^{-1} &= e^{2\beta} \end{aligned} \quad \dots \dots (8)$$

and

$$\begin{aligned} k_0 &= a \frac{\partial f}{\partial a} + a^2 \frac{\partial^2 f}{\partial a^2}, \\ k_1 &= ab \frac{\partial^2 f}{\partial a \partial b}, \\ k_2 &= b \frac{\partial f}{\partial b} + b^2 \frac{\partial^2 f}{\partial b^2}. \end{aligned} \quad \dots \dots (9)$$

3. Calculation of $\rho(E, N)$ when N is very large.

From (5), using (8) we have

$$\begin{aligned} f(\alpha, \beta) &= \sum_{\epsilon=1}^{\infty} \log \left\{ 1 + \frac{1}{e^{\alpha}(e^{\beta\epsilon} - e^{-\beta\epsilon})} \right\} \\ &= - \sum_{\epsilon=1}^{\infty} \log (1 - e^{-2\beta\epsilon}) + \sum_{\epsilon=1}^{\infty} \log (1 + e^{-\alpha - \beta\epsilon}) \\ &\quad + \sum_{\epsilon=1}^{\infty} \log \left(1 - \frac{e^{-2\beta\epsilon}}{1 + e^{-\alpha - \beta\epsilon}} \right). \quad \dots \dots (10) \end{aligned}$$

Now

$$-\sum_{\epsilon=1}^{\infty} \log (1-e^{-2\beta\epsilon}) = \frac{\pi^2}{12\beta} + \frac{1}{2} \log 2\beta - \frac{1}{2} \log (2\pi) + O(\beta). \quad \dots \quad (11)$$

Also

$$\begin{aligned} \sum_{\epsilon=1}^{\infty} \log (1+e^{-\alpha-\beta\epsilon}) &= \sum_{\epsilon=0}^{\infty} \log (1+e^{-\alpha-\beta\epsilon}) - \log (1+e^{-\alpha}) \\ &= \int_0^{\infty} \log (1+e^{-\alpha-\beta\epsilon}) d\epsilon - \frac{1}{2} \log (1+e^{-\alpha}) + \frac{\beta}{12} \frac{e^{-\alpha}}{1+e^{-\alpha}}, \end{aligned}$$

where we have replaced the summation by an integration using the Euler-Maclaurin formula. Consider the integral

$$\int_0^{\infty} \log (1+e^{-\alpha-\beta\epsilon}) d\epsilon = \beta \int_0^{\infty} \frac{\epsilon d\epsilon}{1+e^{\alpha+\beta\epsilon}} = \frac{\beta}{2} \int_0^{\infty} \frac{d}{d\epsilon} (\epsilon^2) \frac{d\epsilon}{1+e^{\alpha+\beta\epsilon}}.$$

Using Sommerfeld's lemma we have

$$\int_0^{\infty} \log (1+e^{-\alpha-\beta\epsilon}) d\epsilon \approx \frac{1}{2\beta} \left(\alpha^2 + \frac{\pi^2}{3} \right),$$

so that

$$\sum_{\epsilon=1}^{\infty} \log (1+e^{-\alpha-\beta\epsilon}) \approx \frac{1}{2\beta} \left(\alpha^2 + \frac{\pi^2}{3} \right) + \frac{\alpha}{2} + \frac{\beta}{12}. \quad \dots \quad (12)$$

Considering the last summation in (10) we have

$$\sum_{\epsilon=1}^{\infty} \log \left(1 - \frac{e^{-2\beta\epsilon}}{1+e^{-\alpha-\beta\epsilon}} \right) = \sum_{\epsilon=1}^{\infty} \left\{ -\frac{e^{-2\beta\epsilon}}{1+e^{-\alpha-\beta\epsilon}} - \frac{1}{2} \frac{e^{-4\beta\epsilon}}{(1+e^{-\alpha-\beta\epsilon})^2} - \dots \right\}. \quad (13)$$

Now

$$\begin{aligned} -\sum_{\epsilon=1}^{\infty} \frac{e^{-2\beta\epsilon}}{1+e^{-\alpha-\beta\epsilon}} &= -\int_0^{\infty} \frac{e^{-2\beta\epsilon}}{1+e^{-\alpha-\beta\epsilon}} d\epsilon + O(e^{\alpha}) \\ &= -\frac{e^{\alpha}}{\beta} \left\{ 1 + \alpha e^{\alpha} - e^{\alpha} + \frac{e^{2\alpha}}{2} \right\} + O(e^{\alpha}). \end{aligned}$$

β is a very small quantity (see equation 18) and $\alpha \rightarrow -\infty$. If we neglect quantities of the order of $\frac{e^{\alpha}}{\beta}$ and less the left side of (13) tends to zero. We thus have from equations (10), (11) and (12)

$$f(\alpha, \beta) = \frac{1}{2\beta} \left(\alpha^2 + \frac{\pi^2}{3} \right) + \frac{\alpha}{2} + \frac{\beta}{12} + \frac{1}{2} \log 2\beta - \frac{1}{2} \log 2\pi + O\left(\frac{e^{\alpha}}{\beta}\right). \quad \dots \quad (14)$$

From (6) and (14) we have

$$\left. \begin{aligned} E &= b \frac{\partial f}{\partial b} = -\frac{1}{2} \frac{\partial f}{\partial \beta} = \frac{1}{4\beta^2} \left(\alpha^2 + \frac{\pi^2}{2} \right) - \frac{1}{4\beta} - \frac{1}{24} \\ \text{and} \quad N &= a \frac{\partial f}{\partial a} = -\frac{\partial f}{\partial \alpha} = -\frac{\alpha}{\beta} - \frac{1}{2}. \end{aligned} \right\} \quad \dots \quad (15)$$

It can be shown easily from (8), (9) and (14) that, to the desired order of approximation,

$$k_0 k_2 - k_1^2 = \frac{\pi^2}{8\beta^4}. \quad \dots \quad (16)$$

Also

$$\alpha N + 2\beta E + f(\alpha, \beta) = \frac{\pi^2}{2\beta} - \frac{1}{2} \log \frac{\pi}{\beta} - \frac{1}{2}. \quad \dots \quad (17)$$

From (15) we have

$$\alpha \approx -\beta N,$$

so that

$$E = \frac{1}{4\beta^2} \left(\beta^2 N^2 + \frac{\pi^2}{2} \right) - \frac{1}{4\beta} - \frac{1}{24},$$

or

$$E - \frac{1}{4} N^2 \approx \frac{\pi^2}{8\beta^2},$$

giving

$$\beta = \frac{\pi^2}{2\sqrt{2\left(E - \frac{1}{4} N^2\right)}}. \quad \dots \quad (18)$$

The expression (7) for $\rho(E, N)$ becomes with the help of (16), (17) and (18)

$$\rho(E, N) = \frac{1}{4} \cdot \frac{1}{\left\{2\left(E - \frac{1}{4} N^2\right)\right\}^{\frac{5}{4}}} \exp \left\{ \pi \sqrt{2\left(E - \frac{1}{4} N^2\right)} \right\}.$$

If Δ denotes the spacing of the individual energy levels (in our case $\Delta = \frac{1}{2}$) the number of partitions $P(n, N)$ of a large number

$$n = \frac{E}{\Delta} = \frac{E}{1/2}$$

into exactly N types is

$$P(n, N) = \frac{\Delta}{4 \left\{ \frac{E}{1/2} - \frac{1}{2} N^2 \right\}^{\frac{5}{4}}} \exp \left\{ \pi \sqrt{\frac{E}{1/2} - \frac{1}{2} N^2} \right\},$$

or

$$P(n, N) = \frac{1}{8(n - \frac{1}{2} N^2)^{\frac{5}{4}}} \exp \left\{ \pi \sqrt{n - \frac{1}{2} N^2} \right\}. \quad \dots \quad (19)$$

The above formula holds only for large values of N and $n \gg \frac{1}{2} N^2$. If we plot $P(n, N)$ against N the maximum is expected to occur somewhere near $N \sim n^{\frac{1}{4}}$ and therefore the formula holds only at the tail end of the curve.

4. Calculation of $\rho(E, N)$ for small N .

We consider the case when α is large and positive. We have

$$f(a, b) = \sum_{\epsilon=1}^{\infty} \log \left(1 + \frac{a}{b^{-\epsilon/2} - b^{\epsilon/2}} \right) = \sum_{\epsilon=1}^{\infty} \log \left(1 + \frac{a}{2 \sinh \beta \epsilon} \right). \quad \dots \quad (20)$$

Also

$$\begin{aligned} N = a \frac{\partial f}{\partial a} &= a \sum_{\epsilon=1}^{\infty} \frac{1}{a + 2 \sinh \beta \epsilon} \\ &= \frac{a}{\beta} \int_0^{\infty} \frac{dx}{a + 2 \sinh x} - \frac{1}{2} + \frac{1}{6} \left(\frac{\beta}{a} \right) + 0 \left\{ \left(\frac{\beta}{a} \right)^3 \right\}. \end{aligned}$$

Now for small values of a ($a \rightarrow 0$ since $a = e^{-\alpha}$) we have

$$\int_0^{\infty} \frac{dx}{a + 2 \sinh x} = \frac{1}{2} \log \left\{ \frac{4-a}{a \left(1 + \frac{a}{4} \right)} \cdot \frac{2+a}{2-a} \right\},$$

so that

$$N = \frac{e^{-\alpha}}{\beta} \left(\log 2 + \frac{\alpha}{2} + \frac{e^{-\alpha}}{4} \right) - \frac{1}{2} + \frac{1}{6} \beta e^{\alpha} + 0 \{ (\beta e^{\alpha})^3 \}. \quad \dots \quad (21)$$

We further have

$$E = b \frac{\partial f}{\partial b} = \frac{1}{2} \sum_{\epsilon=0}^{\infty} \frac{\epsilon \coth \beta \epsilon}{1 + 2e^{\alpha} \sinh \beta \epsilon} - \frac{1}{2} \beta = \frac{1}{2} \int_0^{\infty} \frac{\epsilon \coth \beta \epsilon \cdot d\epsilon}{1 + 2e^{\alpha} \sinh \beta \epsilon} - \frac{1}{4\beta} + \frac{e^{\alpha}}{12}. \quad \dots \quad (22)$$

Denoting the first term in (22) by I and putting $c = 2e^{\alpha}$ we have

$$I = \frac{1}{2\beta^2} \int_0^{\infty} \frac{x \coth x dx}{1 + c \sinh x}.$$

Putting $\sinh x = z/c$, and integrating by parts we have

$$I = \int_0^{\infty} \frac{dz}{(c^2 + z^2)^{1/2}} \log \frac{1+z}{z} dz,$$

or on putting $z = c \tan \theta$,

$$\begin{aligned} I &= \int_0^{\pi/2} \log \left(1 + \frac{\cot \theta}{c} \right) \sec \theta d\theta \\ &= \int_0^{\lambda} (-\log c - \log \tan \theta + c \tan \theta - \frac{1}{2} c^2 \tan^2 \theta + \frac{1}{2} c^3 \tan^3 \theta \dots) \sec \theta d\theta \\ &\quad + \int_{\lambda}^{\pi/2} \left(\frac{\cot \theta}{c} - \frac{\cot^2 \theta}{2c^2} + \frac{\cot^3 \theta}{3c^3} \dots \right) \sec \theta d\theta, \end{aligned}$$

where $\tan \lambda = 1/c$.

Performing the integrations term by term we have

$$\begin{aligned}
 I = & (\sqrt{1+c^2}-c) + \left(\frac{c^2}{4} \log \frac{1+\sqrt{1+c^2}}{c} - \frac{1}{4} \sqrt{1+c^2} \right) + \frac{2c^3}{9} + \frac{1}{9} (1+c^2)^{\frac{3}{2}} \\
 & - \frac{c^2}{3} (1+c^2)^{\frac{1}{2}} + \frac{1}{c} \log (c + \sqrt{1+c^2}) + \frac{1}{2c^2} (1 - \sqrt{1+c^2}) \\
 & + \frac{1}{6c^3} \{ c\sqrt{1+c^2} - \log (c + \sqrt{1+c^2}) \} - \frac{1}{12c^4} \{ 2 - (1+c^2)^{\frac{1}{2}} (2-c^2) \} \\
 & + \frac{1}{c} - \frac{1}{2c^3} \cdot \frac{1}{3^2} + \frac{1 \cdot 3}{2 \cdot 4} \frac{1}{5^2} \cdot \frac{1}{c^5} - \frac{1 \cdot 3 \cdot 5}{2 \cdot 4 \cdot 6} \cdot \frac{1}{7^2} \cdot \frac{1}{c^7} - \dots
 \end{aligned}$$

Hence the expression for E becomes

$$E = \frac{e^{-\alpha}}{4\beta^2} \left\{ 2 \log 2 + \alpha + \frac{11}{12} + \frac{1}{3} \beta^2 e^{2\alpha} - \beta e^{\alpha} \right\}, \quad \dots \quad (23)$$

for values of $c \equiv 2e^{\alpha} \gg 1$.

β is a very small quantity and if we neglect quantities of the order of βe^{α} , (21) and (23) become

$$N = \frac{e^{-\alpha}}{\beta} \left(\frac{\alpha}{2} + \log 2 \right),$$

and

$$E = \frac{e^{-\alpha}}{4\beta^2} \left(\alpha + 2 \log 2 + \frac{11}{12} \right).$$

For large α

$$\left. \begin{aligned} N &\approx \frac{e^{-\alpha}}{2\beta} \cdot \alpha, \\ E &\approx \frac{e^{-\alpha}}{4\beta^2} \cdot \alpha. \end{aligned} \right\} \quad \dots \quad (24)$$

From (6) and (24) we obtain

$$f(\alpha, \beta) \approx \frac{\alpha e^{-\alpha}}{2\beta} = 2\beta E,$$

so that

$$\alpha N + 2\beta E + f(\alpha, \beta) \approx \alpha N + 4\beta E. \quad \dots \quad (25)$$

Also

$$\beta \approx \frac{N}{2E}, \quad \dots \quad (26)$$

and therefore

$$\alpha \approx \log \frac{E}{N^2} + \log \log \frac{E}{N^2}. \quad \dots \quad (27)$$

Using (27) in (25) we get

$$\alpha N + 2\beta E + f(\alpha, \beta) \approx N \left(\log \frac{E}{N^2} + \log \log \frac{E}{N^2} + 2 \right) \approx N \log \frac{E}{N^2} + 2N. \quad \dots \quad (28)$$

It may easily be shown that

$$k_0 k_2 - k_1^2 \approx \frac{\alpha^2 e^{-2\alpha}}{16\beta^4} \approx E^2. \quad \dots \quad \dots \quad (29)$$

Substituting (28) and (29) in (7) we get

$$\rho(E, N) \approx \frac{1}{2\pi} \frac{E^{N-1}}{N^{2N}} e^{2N}.$$

Since the spacing of the levels is $\frac{1}{2}$ (energy units) we have

$$P(n, N) \approx \frac{1}{2\pi} \frac{n^{N-1}}{2^N N^{2N}} e^{2N}. \quad \dots \quad \dots \quad (30)$$

Expression (30) is valid for values of $N \ll n^{\frac{1}{2}}$, i.e., on the left of the maximum of the $P(n, N)$, N curve.

4. Partitions when the types of summands are unrestricted :

In this section we shall consider the case when there is no restriction on the types of summands that can occur. This is achieved by putting $\xi = 1$ in the generating function. We shall in what follows consider only the partitions into integers repeated an odd number of times, since the partitions of $2n$ into integers can be looked upon as the partitions of n into integers and half odd integers. The generating function to be considered is then

$$\begin{aligned} f(x) &= \prod_{i=1}^{\infty} (1 + x^i + x^{3i} + x^{5i} + \dots) \\ &= \left(1 + \frac{x}{1-x^2}\right) \left(1 + \frac{x^2}{1-x^4}\right) \left(1 + \frac{x^3}{1-x^6}\right) \dots \\ &= \frac{(1+x-x^2)(1+x^2-x^4)(1+x^3-x^6) \dots}{(1-x^2)(1-x^4)(1-x^6) \dots}. \quad \dots \quad (31) \end{aligned}$$

We have to find the coefficient of x^n in (31). If this coefficient is denoted by $\omega(n)$ we have* as usual

$$\omega(n) = \frac{e^{z(\mu)}}{\left(-2\pi \frac{\partial n}{\partial \mu}\right)^{\frac{1}{2}}}, \quad \dots \quad \dots \quad (32)$$

where

$$x = e^{-\mu}, \quad n = -\frac{\partial}{\partial \mu} \log f(e^{-\mu}), \quad z(\mu) = n\mu + \log f(e^{-\mu}).$$

Now

$$\log f(e^{-\mu}) = \sum_{r=1}^{\infty} \log (1 + e^{-r\mu} - e^{-2r\mu}) - \sum_{r=1}^{\infty} \log (1 - e^{-2r\mu}). \quad \dots \quad (33)$$

* For a proof see Auluck, F. C., and Agarwala, B. K., *loc. cit.*

But

$$\prod_{r=1}^{\infty} \frac{1}{1-e^{-2r\mu}} = \frac{e^{\pi^2/12\mu}}{\sqrt{\pi}} \sqrt{\mu}.$$

Therefore

$$-\sum_{r=1}^{\infty} \log(1-e^{-2r\mu}) = \frac{\pi^2}{12\mu} + \frac{1}{2} \log \frac{\mu}{\pi}. \quad \dots \quad (34)$$

Again

$$\begin{aligned} \sum_{r=1}^{\infty} \log(1+e^{-r\mu}-e^{-2r\mu}) &= \sum_{r=0}^{\infty} \log(1+e^{-r\mu}-e^{-2r\mu}) \\ &= \int_0^{\infty} \log(1+e^{-\mu x}-e^{-2\mu x}) dx + \int_0^{\infty} P_1(x) \frac{\mu(2e^{-2\mu x}-e^{-\mu x})}{1+e^{-\mu x}-e^{-2\mu x}} dx, \end{aligned}$$

where

$$P_1(x) = x - [x] - \frac{1}{2} = -\sum_{n=1}^{\infty} \frac{\sin n\pi x}{n\pi}.$$

Therefore

$$\sum_{r=1}^{\infty} \log(1+e^{-r\mu}-e^{-2r\mu}) = \int_0^{\infty} \log(1+e^{-\mu x}-e^{-2\mu x}) dx - \frac{1}{12} \mu + O(\mu^3). \quad \dots \quad (35)$$

Denoting the integral on the right-hand side by I_1 and putting $e^{-\mu x} = \sin^2 \theta$, we have

$$\begin{aligned} I_1 &= \frac{2}{\mu} \int_0^{\pi/2} \log(1+\sin^2 \theta \cos^2 \theta) \cot \theta d\theta \\ &= \frac{1}{\mu} \int_0^{\pi/2} \frac{\log(1+\sin^2 \theta \cos^2 \theta)}{\sin \theta \cos \theta} d\theta \\ &= \frac{1}{\mu} \int_0^{\pi/2} \left\{ \sin \theta \cos \theta - \frac{1}{2} \sin^3 \theta \cos^3 \theta + \frac{1}{3} \sin^5 \theta \cos^5 \theta - \dots \right\} d\theta \\ &= \frac{1}{\mu} (.46313). \quad \dots \quad (36) \end{aligned}$$

Substituting (34), (35), (36) in (33) we have

$$\log f(e^{-\mu}) = \frac{\gamma^2}{\mu} + \frac{1}{2} \log \left(\frac{\mu}{\pi} \right) + O(\mu), \quad \dots \quad (37)$$

where

$$\gamma^2 = \frac{\pi^2}{12} + .46313.$$

From (37) we have

$$n = -\frac{\partial}{\partial \mu} \log f(e^{-\mu}) = \frac{\gamma^2}{\mu^2} - \frac{1}{2\mu},$$

which gives

$$\mu \approx \frac{\gamma}{\sqrt{n}} - \frac{1}{4n}.$$

For $z(\mu)$ we get

$$\begin{aligned} z(\mu) = n\mu + \log f(\mu) &= n\left(\frac{\gamma}{\sqrt{n}} - \frac{1}{4n}\right) + \frac{\gamma^2}{4\gamma^2} (1 + 4\gamma\sqrt{n}) + \frac{1}{2} \log\left(\frac{\gamma}{\sqrt{n}} - \frac{1}{4n}\right) \\ &\quad - \frac{1}{2} \log \pi + O(\mu) \approx 2\sqrt{n}\gamma - \frac{1}{2} \log \frac{\pi}{\mu} \quad \dots \quad \dots \quad \dots \quad (38) \end{aligned}$$

Also

$$-\frac{\partial n}{\partial \mu} = \frac{2\gamma^2}{\mu^3} - \frac{1}{2\mu^2} \quad \dots \quad \dots \quad \dots \quad \dots \quad (39)$$

Using (38) and (39) in (32) we obtain

$$\omega(n) = \frac{\gamma}{2\pi n} e^{2\gamma\sqrt{n}} = \frac{1.134}{2\pi n} \exp \{2.268\sqrt{n}\}. \quad \dots \quad \dots \quad (40)$$

The partitions into integers and half odd integers can be obtained from (40) by replacing n by $2n$ so that

$$P(n) = \frac{1.134}{4\pi n} \exp \{3.206\sqrt{n}\}.$$

$P(n)$ thus represents the partitions of n into integers and half odd integers repeated only an odd number of times.

Our thanks are due to Professor D. S. Kothari, for his keen interest and helpful discussions during the course of this work.

REFERENCES.

- Auluck, F. C. and Kothari, D. S. (1946). Statistical mechanics and the partitions of numbers. *Pro. Camb. Phil. Soc.*, **42**, 272.
 Auluck, F. C. and Kothari, D. S. (1946-47). Partitions into powers of integers. *Proc. Roy. Irish. Acad.*, Minutes of Proceedings, Session 1946-47, 13.
 Auluck, F. C. and Agarwala, B. K. Partitions into non-integral powers of integers (in Press).
 Agarwala B. K. Restricted partitions into non-integral powers of integers (in Press).
 Schrödinger, E. (1940). Statistical thermodynamics, Cambridge, 83-84.
 Lier, C. Van and Uhlenbeck, G. E. (1937). On the statistical calculation of the density of the energy levels of the nuclei. *Physica*, **4**, 531.

DEVELOPMENTAL STUDIES.

A COMPARATIVE ACCOUNT OF THE ORIGIN, DEVELOPMENT AND MORPHOLOGY OF THE STIPULES OF *Artocarpus integrifolia* L., *Ficus religiosa* L. and *Ficus elastica* Roxb.

By GOPAL CHANDRA MITRA, Calcutta.

(Communicated by Prof. G. P. Majumdar, Ph.D., F.N.I., F.A.Sc.)

(Received June 24; read August 5, 1949.)

Stipules in the family *Moraceae* have attracted the attention of botanists, particularly of the morphologists, since very early times. Trécul (1846) noted in the family *Artocarpae* (= *Moraceae*) all stages of stipules from single to a pair to each leaf, their axillary and free positions, their enormous development in some cases and their horizontal and oblique insertions on the axis. Hooker (1885) considered the huge stipules of *Ficus elastica* with their 'close parallel nervation (almost resembling that of Monocotyledons) as unmistakable diagnostic character of the species'. Porter (1891) noted the protective function of these structures in the species of *Artocarpus* in the temperate and tropical countries. In 1895, Lubbock published his classical work on the Stipules, their form and function. In 1897, Tyler published his dissertations on the nature and origin of stipules. In these two works all facts known till then have been incorporated. Tyler quotes a very interesting observation of Colomb (1886) who regards the sheathing stipules of *Ficus* and *Magnolia* as transitional stages between ochrea and stipules proper. In his later publication (1887) he regards them as axillary ligule.

Goebel (1905) distinguished the single stipule of *F. elastica* as an axillary stipular sheath, and those of *A. integrifolia* as a pair of free stipules. According to him the earlier the union by the transverse cushion (a new formation) takes place, the more the axillary stipules appear as a single structure, and if the stipules become united also upon the side opposite to the point of insertion of the leaf, a closed sheath must be formed. Besides noting the transverse cushions at the node, Goebel, it appears, has not studied the contributions of these structures to the development of stipules in these species.

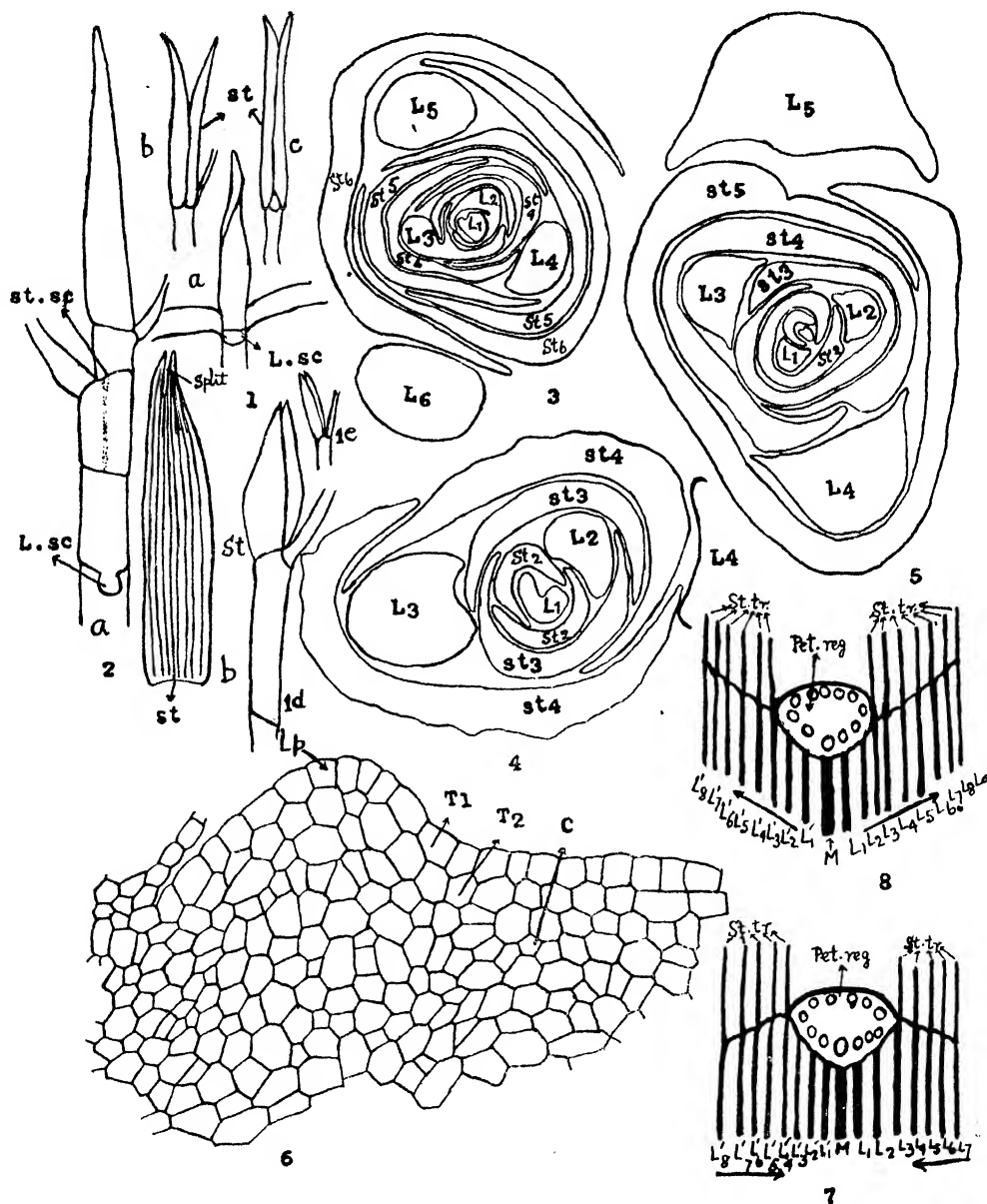
The stipules of *A. integrifolia*, *F. religiosa* and *F. elastica* have been described as bud scales or tegmenta in our general botanical text-books and manuals (Asa Gray, 1879; Green, 1897; Vines, 1910; Strasburger, 1930; Priestley and Scott, 1938; and others). Bud scales are scale-like foliar organs which invest the resting bud (Foster, 1929, pp. 126) and almost any part of a leaf may develop into a bud scale (Priestley and Scott, 1938).

With the exception of Goebel who has mentioned about the early or late fusion by the transverse cushion as determining the nature of the stipules in these plants, the author is not aware of any literature dealing with a detailed ontogeny and development of these structures, and the present communication records the result of such studies so that their morphological nature may be best understood.

Methods of studies have been the same as in previous communications (Mitra, 1945, 1948, 1949). All outline drawings and cellular details have been drawn under a camera lucida with magnifications noted against each figure.

EXTERNAL MORPHOLOGY.

Leaves of *A. integrifolia* and *F. religiosa* possess a pair of stipules each. The position, attachment and the scars of the stipules on the axis are similar in both the species (Figs. 1a-e). They fall off very soon with the unfolding of the leaves and a circular but downwardly oblique scar is left at the node. The stipular scar appears



TEXT-FIGS. 1 to 8.

(See foot of p. 159 for Explanation.)

cauline and is not continuous with the leaf scar (cf. *Morus*, Cross, 1937). Figures 3 and 4 show arrangements of stipules and leaf primordia in a cross-section of a terminal bud in each case. A pair of stipules overlap each other by both their margins and enclose within them successive younger leaves and their stipules.

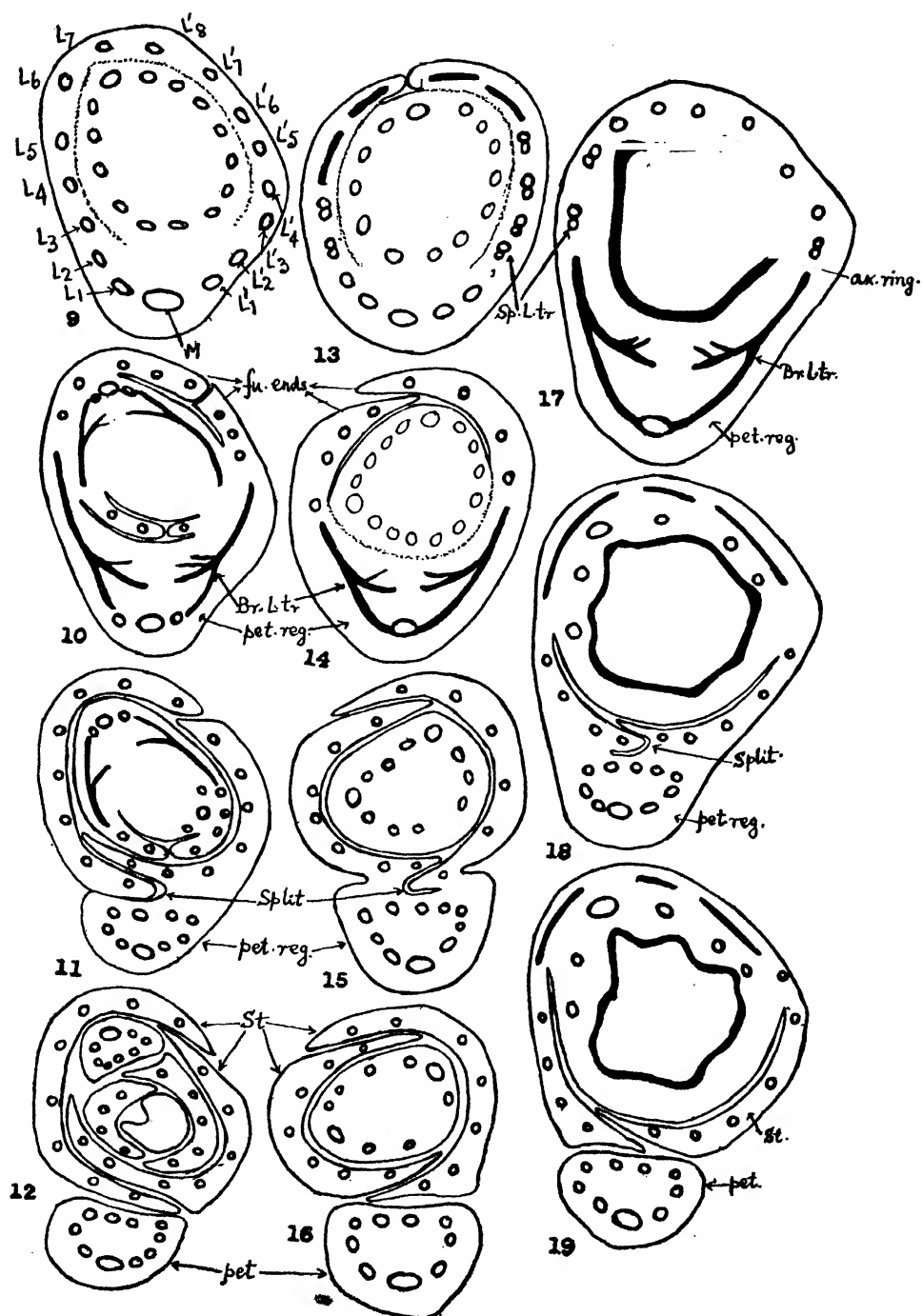
Leaves of *F. elastica*, on the other hand, possess a single stipule each (Figs. 2, a and b). Each stipule has a short, longitudinal split at its apex along the line of fusion of the anterior edges and is much bigger and robust in size and texture than the stipules of the other two species. Figure 5 shows arrangement of stipules and leaf primordia in a cross-section of a terminal bud. The stipular scar is formed around the axis and is obliquely extended into the upper internode, much above the insertion of the petiole of the leaf to which the stipules belong. The leaf-bases in all the three species are either imperceptibly free (*A. integrifolia* and *F. religiosa*), or not at all (*F. elastica*), from the axis. In the case of *F. elastica* the stipule opens only at its posterior margins, whereas in the other two cases the pair of stipules open both at their posterior and anterior margins.

ORIGIN AND EARLY DEVELOPMENT OF THE LEAF PRIMORDIUM.

Figure 6 is a median longisection through the apex of a vegetative bud of *F. religiosa*. Similar sections through the shoot apices of the other two species show similarity in cellular organization and in the origin of leaf primordia. The meristem at the shoot apex consists of two tunica layers (T_1 and T_2) and a corpus (C) without any evident zonation. When a leaf is initiated transverse extension of the apical dome takes place in a particular sector. This extension is brought about by anticlinal divisions in the two layers of the tunica. This is closely followed by simultaneous periclinal divisions in the inner tunica derivatives and the outer corpus layer of this region resulting in a hump like outgrowth on the side of the apical dome (leaf emergence) (Fig. 6). The erection of the primordium progresses under the influence of the acropetally differentiating desmogen strand (its median bundle) coming up from the axial ring. The protoxylem is seen to differentiate in this desmogen strand at the base of the free limb and its progressive differentiation is acropetal in the latter and basipetal in the axis. Later on, as many as 15 or 17 lateral trace bundles enter the two arms of the base of the primordium as it extends tangentially around the axis. The two arms of the base at this stage show unequal

EXPLANATION OF TEXT-FIGS. 1-8 (p. 158).

1. a-c. Terminal buds of *F. religiosa* (Figs. a-c) and *A. integrifolia* (Figs. d-e), showing leaf scar (L.sc.) and the insertions of stipules at the nodes. Fig. d—stipules enclosing the shoot apex and the inflorescence while Fig. c—stipules enclosing the shoot apex only. All— $\frac{2}{3}$ Nat. Size.
2. a and b. Terminal bud of *F. elastica*; a, showing stipular scar (st.sc.) and leaf scar (L.sc.) and b, showing a single stipule (st.) with a split at its apical region and its parallel nervation. $\frac{2}{3}$ Nat. Size.
3. Transsection of a terminal bud of *F. religiosa*. L_1, L_2, L_3, L_4, L_5 and L_6 are leaf primordia with their corresponding stipules ($st_1, st_2, st_3, st_4, st_5$ and st_6). $\times 11$.
4. Transsection of a terminal bud of *A. integrifolia*. L_1, L_2, L_3 and L_4 are leaf primordia with their corresponding stipules (st_1, st_2 , etc.). $\times 31$.
5. Transsection of a terminal bud of *F. elastica*. L_1, L_2 , etc., are leaf primordia with their corresponding stipules (st_1, st_2 , etc.). $\times 11$.
6. A median longisection of *F. religiosa* showing cellular organisation and initiation of leaf primordium (Lp) at the apex. T_1 and T_2 —the outer and inner layers of tunica respectively and C—the corpus. For explanation see text. $\times 477$.
7. Showing courses of the median (M) and the lateral traces (L_1, L_2 , etc., and L'_1, L'_2 , etc.) in the axial component of *F. religiosa* in a split condition.
The splitting of the median trace has not been shown. Arrow indicates the progress of branching of the laterals of the arms and their gradual linking up. For explanation see text. Pet. reg.—central region of the base and st.tr.—stipular trace. Diagrammatic.
8. Showing courses of the median (M) and the lateral traces (as indicated by numbers in Fig. 7) in the axial component of *F. elastica* in a split condition. The splitting of the median trace has not been shown. Arrow indicates the progress of branching of the laterals of the arms and their gradual linking up. For explanation see text. Diagrammatic.



TEXT-FIGS. 9 to 19.

(See foot of p. 161 for Explanation.)

development and this appears to be due to unequal number of laterals (consequently food supply) they receive from the axial ring. The leaf-base shows considerable radial extension of its central region containing the median and immediate lateral traces.

Figures 11, 15 and 19 show that the base is never free (*F. elastica*) or free only for a very short length (*F. religiosa* and *A. integrifolia*) from the axis. The leaf-base, therefore, in these species, forms a thick mantle (skin) round the axis (internode); it grows and elongates unitedly with the growth and elongation of the axial core by intercalary growth of their cells. The internode in these species is thus made up of an axial core and a thick skin which belongs to the leaf. The base and the axial-component of the leaf are equivalent structures in each case and to an external morphologist the leaves of these species appear to consist of the blade and the petiole without any base, and it becomes difficult on external morphology alone to conceive the bud scales as leaf-base outgrowths, i.e., stipules.

ORIGIN OF THE STIPULES.

The leaf-base in *F. religiosa* and *A. integrifolia*, as we have just seen grows united with the axial core for the most part. During this united growth, the two laterally extending arms of the base meet and fuse on the side of the axis opposite to the median trace. After the fusion has been effected a branch from each of the extreme laterals L_7 and L'_8 (Figs. 7 and 13) enters this end. Then an oblique split appears between these two branches in the manner shown in figures 10 and 13 causing a separation of the fused ends which then overlap (Figs. 11 and 14). Separation of the base from the axis now proceeds from this end towards the central region of the base; its progress is always preceded by branches of corresponding laterals entering the arms (Figs. 11 and 15).

By the time a complete separation of the leaf-base is effected from the axis, the median and its branches, the laterals in the central region and branches coming from the proximate laterals of the arms, arrange themselves in the form of a ring in this region and a split now occurs on its adaxial side (Figs. 11 and 15). The split then extends both ways and the two arms not only become free from the axis and from each other but also cut off portions from the central region of the base which now develops as the petiole (Figs. 12 and 16).

The two arms thus being free grow directly into a pair of stipules without any pre-formed primordia. The vascular system of the stipules is formed by the branches of the laterals which run parallel to one another.

In *F. elastica*, on the other hand, after the fusion of the two laterally extending arms of the base, the regions of the arms adjacent to the central region of the base, but not the fused ends, are the first parts to receive branches from the laterals in

EXPLANATION OF TEXT-FIGS. 9-19 (p. 160)

9-12. Serial transections of the shoot apex of *F. religiosa* showing the separations of the fused ends (fu. ends), of the base from the axis and of the arms from the central region; the origin of stipules (st) and the courses of the median (M) and the lateral traces (indicated by numbers) in the base of a primordium. pet.—petiole. For explanation see text. Br.L.tr.—branching of lateral traces.

Fig. 9 is 110μ below the extreme tip; Fig. 10, 20μ above Fig. 9; Fig. 11, 30μ above Fig. 10; and Fig. 12, 40μ above Fig. 11. Each $\times 50$.

13-16. Serial transections of the shoot apex of *A. integrifolia*. Description as given for the figures 9-12.

Fig. 13 is 170μ below the extreme tip; Fig. 14, 30μ above Fig. 13; Fig. 15, 40μ above Fig. 14; and Fig. 16, 20μ above Fig. 15. Each $\times 50$.

17-19. Serial transections of the shoot apex of *F. elastica* showing separation of the fused arms of the base from the axis and from the central region (pet.reg.); the origin of a single stipule and the courses of the median and lateral traces through the axial component. ax.ring—axial ring of vascular bundles; Br.L.tr.—branching of the lateral traces. Fig. 17 is 770μ below the extreme tip; Fig. 18, 250μ above Fig. 17; and Fig. 19, 110μ above Fig. 18. Each $\times 19$.

this region and separate from the axis from this end. Meanwhile, the median and its branches, the laterals and their branches arrange themselves in the form of a ring in the central region of the base and its separations from the axis and into the petiole and the stipule, commence simultaneously. Separation of the base from the axis proceeds towards its opposite side and its progress is always preceded by the branches of the laterals entering the arms one after the other. While the base is becoming free from the axis the arms cut off portions from the central region of the base in the manner as described for the other two species. These cut ends (posterior) of the arms then grow and overlap and finally the arms separate from the axis as one piece without any split at the fused ends. The two arms thus being free as one piece with its overlapping posterior margins develop as a single stipule and the central region of the base as the petiole (Figs. 5 and 19). Thus it is seen that though the number of stipules in this species is one, it is a product of the two arms of the base. The stipular scar is also obliquely circular but the inclination is in this case upwards. Vascular system is formed exclusively, as in the other two species, by the branches of the laterals which run parallel to one another.

COURSES OF THE LEAF TRACES IN THE BASE OF THE LEAF AND THE VASCULAR SYSTEM OF THE STIPULES.

The node in each species is multilacunar, one median and 15 or 17 laterals enter the base which grows unitedly with the axial core. The median and the laterals depart from the axial ring, but instead of deviating at once towards the periphery they take vertical courses and form an outer series of bundles in the internode (Figs. 9, 13 and 17). The median continues its vertical course for some distance and then spreads laterally by giving off branches on its sides. Below the nodal region the median, its branches and 2 or 3 laterals on each side (L_1 , L_2 , and L'_1 , L'_2 and L'_3 , Fig. 7) enter directly the central region of the base. Up to this point the course of events is similar in all the three species but the subsequent behaviour of the remaining laterals is different in them.

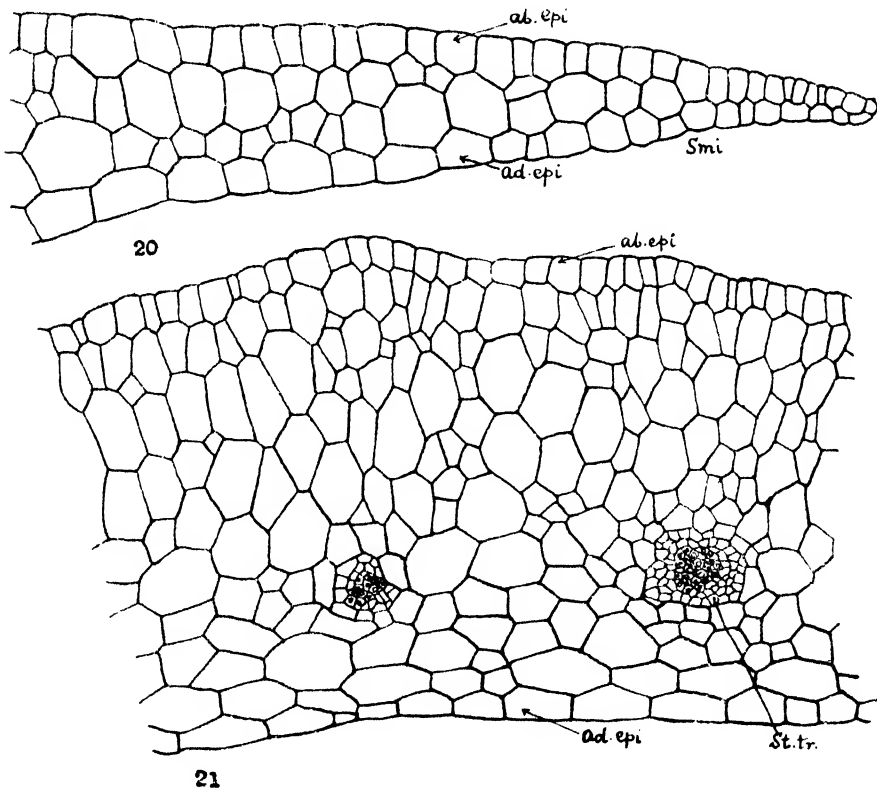
In *F. religiosa* and *A. integrifolia* the remaining laterals begin to split one after the other, the splitting commencing from those at the extreme ends of the two arms. L_7 and L'_8 split simultaneously, one set of branches follows an oblique horizontal course to join L_6 and L'_7 respectively, while the other set continues through the fused ends which now begin to separate from the axis. L_6 and L'_7 then split in their turn and one set of their branches goes into the arms and the other set bends and joins L_5 and L'_6 respectively. In this way all the laterals (L_7 to L_3 and L'_8 to L'_4) are linked up with one another by their branches (Fig. 7), not at the same level but at different heights with the result that though they form a complete girdle round the axis, they are seen detached in a transverse section (Fig. 13).

L_3 and L'_4 are the last two of the laterals to split in the arms. In each case, one of the branches, as usual, goes into the arms and the other on entering the central region bifurcates: one branch of L_3 unites with L_2 and the other moves to the adaxial side and split here (Figs. 10 and 14). Same thing happens in the case of L'_4 . These ultimate branches unite with each other. Thus the median, its branches, the laterals and their ultimate branches form a ring of vascular bundles in the central region of the base. By the time the leaf-base has completely separated from the axis. There now occurs an oblique split on the adaxial side of the leaf base which progresses both ways until the two arms completely cut off portions from the central region. The posterior margins of the two free arms now grow and overlap each other (Figs. 12 and 16).

In *F. elastica*, on the other hand, the oblique horizontal linking up of the split halves of the laterals starts from near the central region of the base and proceeds towards the fused ends of the arms. The organization of the vascular ring in the central region and the commencement of the branching of the laterals and their

linking up to form a girdle around the axis take place in an order reverse of what has been described for the other two species. The separations of the base from the axis and of the arms from the central region by the formation of a split begin simultaneously at this end (Figs. 18 and 19), and the former proceeds towards the opposite side. As the progress of separation is contingent on the branching of the laterals by turn its beginning and completion, therefore, take place at different heights of the axis (Figs. 5, 8 and 17).

In all the three species the arms of the leaf-base directly develop as a *pair* or a *single* stipule as the case may be under the influence of the branches of the laterals going straight into these organs while the other set by linking up with one another form the oblique horizontal girdle round the axis. It is also to be noted that the arms cut off portions from the central region of the base only after the median, its branches, the laterals and their branches have arranged themselves in the form of a ring. The separation of the base from the axis starts with the running of branches from the pair of laterals to branch in the arms first and is completed with the



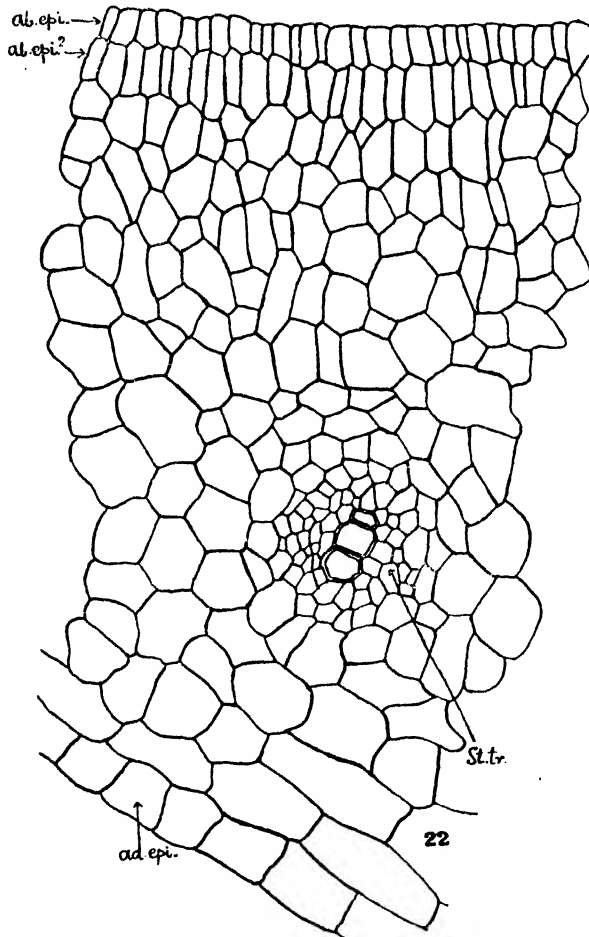
TEXT-FIGS. 20-21.

20. Transection through the margin of a stipule showing marginal growth. ab.epi.—abaxial epidermis. ad.epi.—adaxial epidermis, and Smi.—submarginal initial. For explanation see text. $\times 460$.
21. Transection of a mature stipule of *F. religiosa* through the median region of the lamina showing cellular differentiation and vascular bundles. ab.epi.—abaxial epidermis; ad.epi.—adaxial epidermis and st.tr.—stipular trace which is a branch of a lateral trace. $\times 223$.

branches from the pair to remain and split in the arms last. The formation of a stipule takes place by gradual separation of the arms of the leaf-base and without any pre-formed primordium which might be identified as stipular primordium.

TISSUE DIFFERENTIATION IN THE STIPULES.

In all the three species marginal growth of the stipules takes place in the same manner. The marginal meristem (*perinome* of Lund, *vide* McNab, 1873) is continuous over the edge and by dividing anticlinally forms the adaxial and abaxial epidermi. At the extreme edge, however, the marginal meristem forms a biseriate plate of cells (Fig. 20). The submarginal meristem (*pycnome* of Lund, *vide* McNab, 1873) divides periclinally, and subsequent oblique divisions of the derivatives give



TEXT-FIG. 22.

22. Transection of a mature stipule of *F. elastica* near the median region of the lamina showing the cellular differentiation and vascular bundle. ab.epi.—abaxial epidermis; ab.epi.²—second layer of abaxial epidermis; ad.epi.—adaxial epidermis and st.tr.—stipular trace. $\times 49^\circ$.

rise to the many layered mesophyll (Fig. 21). In *F. elastica* the abaxial subepidermal cells divide regularly by anticlinal walls and appear as a second layer of epidermis (Fig. 22). The mesophyll of the stipule is not differentiated into the spongy and palisade tissues (Figs. 21 and 22). The vascular system of the stipules, as we have already seen, is made up of branches from the laterals running parallel to one another.

DISCUSSION.*

Developmental studies of the vegetative shoot apices of the three species of *Moraceae*, namely *Artocarpus integrifolia*, *Ficus religiosa* and *Ficus elastica*, show that though they present similarity in cellular organization, foliar initiation and internodal development, *F. elastica* differs from the other two species in the method of origin of the stipules and their separation from the axis.

The stipules in these species have no separate primordia, but the arms of the leaf base including the adaxial portions of its central region, as they separate from the axis, develop into these structures. The separation is gradual because the branches of the laterals enter the arms one after the other and not simultaneously, and that is why the stipular scar is oblique instead of being horizontal in these cases.

Stipules are leaf-base divergences. In *F. elastica* the studies show the absence of a free base, though in the other two species its development is very slight, almost imperceptible to the naked eye. It appears that most of the previous workers have not taken into their consideration the axial-component of the leaf while describing the origin and development of a leaf primordium. Our studies show that the axial-component cannot be omitted from the studies of leaf development. They prove conclusively that the base of the leaf may be (1) completely incorporated in the axis, i.e., internode, as is illustrated in *F. elastica* (cf. also *Paederia foetida*, Mitra, 1948); (2) for the most part included in the axis, and free for a very short length, as in *F. religiosa* and *A. integrifolia*; and (3) partly included in the axis, but free for some considerable length, as in *Heracleum* (Majumdar, 1942, 1947 and 1949), *Polygonum* (Mitra, 1945), *Rosa* (Mitra, 1949), and others with free sheathing bases.

If stipules are leaf-base divergences, and they certainly are, unless the axial-component is recognized as a part of the leaf-base, *bud scales* of these species, and particularly of *F. elastica*, cannot be regarded as stipules. Therefore, we are perfectly justified in recognizing the base as comprising of two regions: one incorporated into the axis (axial-component), and the other free. The free portion is very slightly developed in *F. religiosa* and *A. integrifolia*, and undeveloped in *F. elastica*.

The origin and behaviour of the leaf traces and their branches also support the conclusion that the axial-component is a part of the leaf-base. It can be safely postulated that the laterals branch only in the leaf-base below the petiole and beyond the petiole in connection with the development of leaflets and lamina. The branches in the leaf-base cause the development of its laminar wings, teeth or stipules, and in their absence these structures will not develop in the base. In our studies we find the laterals branch in the axial-component, and one set of branches stimulate the arms of the latter beyond the level of branching to develop further into the stipules. All these facts show that the axial-component of a leaf is part and parcel of its base. Moreover, the courses of the laterals after departing from axial ring determine the nature of the base whether it will continue its united growth with the axis for a short or greater length, or be immediately free from the latter and give rise to simple or sheathing leaf-bases.

Saunders in 1922 revived the Berindung Theory of Hofmeister (1851) and propounded her Leaf-skin Theory, both of which visualized a core (axial) and a skin

* In this discussion leaf-base and axial-component are used synonymously.

(leaf-base), the radial, tangential and vertical extent of the latter varying. According to Hofmeister all the tissues external to the pith belong to the leaf. Saunders, on the other hand, thinks the epidermis and one or two hypodermal layers belong to this organ. The present studies, however, support the view of Hofmeister.

According to Saunders the leaf-skin is formed by a downward growth and extension of the leaf primordium keeping pace with the extension of the central axis with which it is fused. This is not supported by our observation. We have seen that the axial-component soon after its initiation encloses the axial core and later in ontogeny by their united intercalary growth the internode is developed. In this connection the observation of Sharman (1942) on the development of the internode of Maize from the lower half of the 'disc of insertion' of the primordium may be referred to. Once more the dual nature of the axis (leaf-base+axial core) is revived. It is desirable that further extensive developmental studies should be made to establish the true morphology of the axis.

It is proved once again that the branches of the lateral traces are the determining factor for the development of the stipules from the leaf-base. Normally a stipulate leaf has a pair of stipules and they diverge symmetrically from the base on the two sides of the petiole. Stipules of *F. religiosa* and *A. integrifolia* conform to this rule, and in *F. elastica* though a single stipule is formed the developmental studies establish its double nature, i.e., the product of the fusion of the two arms which do not free and overlap in the region of fusion of their ends. Its double nature is also indicated by the short split at the apical portion of the adult stipule along the line of fusion.

It is difficult to suggest any explanation as to why the fused margins in this case do not separate and overlap in the manner noticed in the other two species, unless the nature of the splitting is different. In all the three cases the wings or arms of the base meet on the opposite side of the axis and remain united with the latter for some length. In their subsequent development *F. elastica* differs from the other two species in one important aspect, namely, that the branching of the laterals and the separation of the base from the axis, as we have noticed, take place in reverse order.

The stipules of these species have been described as axillary by Goebel and others but their ontogeny, however, shows that they are lateral outgrowths, only a portion, i.e., the extreme posterior margins is derived from the central region of the base.

SUMMARY.

Developmental studies of the vegetative shoot apices of the three species, namely *Artocarpus integrifolia*, *Ficus religiosa* and *Ficus elastica* show similarity in cellular organization and in the initiation and early development of leaf primordia.

During foliar development the two sides of the axial-component extend tangentially around the apical dome and completely enclose the latter. They meet on the opposite side of the axis and fuse with each other by their ends. At first, the median and then gradually 7 or 8 laterals on each side of the median enter the axial-component as its two arms extend round the axis. These trace bundles, median and laterals, instead of diverging at once towards the periphery of the axial-component which now invest the axis in the form of a mantle (skin), follow upward courses and form an outer series of bundles surrounding the axial ring. The internode is developed later by the intercalary growth of the axial-component and the central core of the axis as one organ.

All these features concerning the origin and development of leaf primordia and the internode up to a point are common to all the three species but the subsequent development and differentiation is different in them.

In *A. integrifolia* and *F. religiosa* the branching of the laterals, which is not simultaneous but takes place one after the other begins with the pair of laterals at the extreme ends of the two arms and stops with the laterals just outside the central region of the base. Of the two branches of each lateral one goes up into the arms and the other bends obliquely to join the lateral next to it. In this way all the laterals of the arms are linked up gradually by one set of their branches to form an oblique horizontal girdle round the axis, the other set goes directly into the arms of the base above the region of branching. By this time radial extension

of the central region of the base in the form of an abaxial bulge has formed due to the activity of the abaxial meristem.

The branching of the laterals is followed by the separation of the base from the axis which begins at the fused ends. An oblique split occurs at this end and later development of the split ends cause their overlapping. Vertical growth of the axis (i.e., of the combined axial-component and central core) continues until a complete separation of the base from the axis is effected. By this time the median, its branches, the laterals and their branches have arranged themselves in the form of a ring in the central region of the base—a feature characteristic of a cylindrical petiole. An oblique adaxial split now occurs at this region which cause overlapping of the split margins. The free arms now cut off portions from the central region of the base and the three organs, viz., the central region and the two free arms overlapping by both their margins continue their vertical growth and development under the influence of their respective vascular supply as the petiole and a pair of stipules respectively. The pair of stipules enclose and protect the buds as bud scales. The stipular scar is obliquely circular, the inclination being towards the lower internode.

In *F. elastica* the story of the branching of the laterals and the separation of the base from the axis, is the reverse of what has been noticed in the above two species. The branching of the laterals begins at the central region of the base and proceeds from one lateral to the other by turn towards the opposite side of the axis. In a similar way, as what has been noticed in the other two species, one set of branches of the laterals run vertically into the arms and the other set link up with one another to form an oblique horizontal girdle round the axis. The central region, as in the other two species, grows radially in the form of a bulge.

The separation of the base from the axis and of the arms from the central region begin at the latter region but not at the fused ends of the arms as is seen in the other two species, and after the first pair of branches of the laterals have entered the arms and the median, the laterals and their branches have arranged themselves in the form of a closed ring in the central region of the base. The separation then proceeds towards the opposite side of the axis. The fused arms with its posterior margins overlapping and except for a very short split at its apex, separate as one piece from the axis with the result that the stipule is single and sheathing in this species. The posterior margins of the stipule which are adaxial portions of the central region of the base being cut off in a manner as described for the other two species, due to active growth overlap each other and enclose and protect the buds as bud scales. The stipular scar is obliquely circular but the inclination is towards the upper internode.

The present studies prove that —

- (1) The leaf-base includes the axial-component which should be regarded as an integral part of the leaf:
 - (i) when it consists of the axial-component only as in *F. elastica* the free base is absent;
 - (ii) when it is axial-component for the most part and free only for a very short length as in *F. religiosa* and *A. integrifolia*, the base has just a free portion;
 - and (iii) when it is axial-component for comparatively a short length (leaf cushion) and free for a considerable length as in *Heracleum*, *Polygonum*, etc., the free portion of the base is sheathing.
- (2) The internode of the axis is structurally dual in nature being composed of an axial core enveloped by the axial-component (base or bases of leaves).
- (3) For the development of stipules branches from the lateral traces are essential but pre-formed primordia are not necessary.

ACKNOWLEDGMENTS.

The author is indebted to Prof. G. P. Majumdar, Ph.D., F.N.I., Professor of Botany, Presidency College, Calcutta, for his guidance in the work and for valuable assistance in preparing the manuscript.

LITERATURE.

- Colomb, G. (1886). Note sur l'ochrea des Polygonees. *Bull. Soc. Bot. Fr.*, **33**, 506-507.
 (Quoted from Tyler.)
 ——— (1887). Recherches sur les stipules. *Ann. Sci. Nat.* (V11), **6**, 1-76. (Quoted from Tyler.)
 Cross, G. L. (1937). The origin and development of the foliage leaves and stipules of *Morus alba*. *Bull. Torrey Bot. Club*, **64**, 145-163.
 Foster, A. S. (1928). Salient features of the bud scale morphology. *Biol. Rev.*, **3**, 123-164.
 Goebel, K. (1905). *Organography of Plants*. Pt. II. Eng. Trans. Oxford.

- Gray, A. (1879). Botanical Text-book. I. Structural Botany. New York.
- Green, J. R. (1897). A Manual of Botany. Vol. I. London.
- Hofmeister, W. (1851). Vergl. Untersuchungen. (Quoted from Saunders.)
- Hooker, Sir J. D. (1885). Flora of British India. Vol. V. London.
- Lubbock, Sir John (1895). On Stipules, their Form and Functions. Part II, *Journ. Linn. Soc. Bot.*, **30**, 463-532.
- Majumdar, G. P. (1942). The organisation of the Shoot in *Heracleum* in the Light of Development. *Ann. Bot.*, N.S., **6**, 49-81.
- (1947). Growth unit or the phyton in Dicotyledons with special reference to *Heracleum*. *Bull. Bot. Soc., Bengal*, **1**, 61-66.
- (1949). Leaf development at the growing apex and phyllotaxy in *Heracleum*. *Proc. Ind. Acad. Sci.*, **28**, 83-98.
- McNab, W. R. (1873). Review of Samsøe Lund's monograph. *Journ. Bot.*, N.S., **2**, 184.
- Mitra, G. C. (1945). The origin, development and morphology of the ochrea in *Polygonum orientale* Linn. *Journ. Ind. Bot. Soc.*, **24**, 191-200.
- (1948). Developmental Studies. The interpetiolar stipules of *Rubiaceae* with special reference to *Paederia foetida* Linn. and *Ixora parviflora* Vahl. *Journ. Ind. Bot. Soc.*, **27**, 150-166.
- Mitra, G. C. (1949). The origin, development and morphology of adnate stipules in *Rosa centifolia* Linn. *Journ. Ind. Bot. Soc.*, **28**, 68-83.
- Priestley, J. H. and Scott, L. I. (1938). An Introduction to Botany. London.
- Potter M. C. (1891). Observations on the Protection of Buds in the Tropics. *Journ. Linn. Soc. Bot.*, **28**, 343-352.
- Saunders, E. R. (1922). Leaf-Skin Theory of the Stem. *Ann. Bot.*, **36**, 135-165.
- Sharman, B. C. (1942). Developmental anatomy of the shoot of *Zea mays* L. *Ann. Bot. N.S.*, **6**, 245-282.
- Strasburger, E. (1930). A text-book of Botany. Eng. Trans. London.
- Trécul, A. (1846). Memoire sur la famille des Artocarpees. *Ann. Sci. Nat. Ser.*, **3**, 13.
- Tyler, A. A. (1897). The Nature and Origin of Stipules. *Ann. N.Y. Acad. Sci.*, **10**, 1-49.
- Vines, S. H. (1910). An Elementary Text-book of Botany. London.

BREEDING HABITS, EGGS AND EARLY LIFE HISTORY OF THE INDIAN SHAD, *HILSA ILISHA* (Ham.), IN THE NARBADA RIVER.

By C. V. KULKARNI, *M.Sc., Ph.D., Department of Fisheries, Bombay.*

(Communicated by Dr. S. B. Setna, F.N.I.)

(Received February 2; read March 3, 1950.)

CONTENTS.

	<i>Page</i>
Introduction	169
Spawning grounds of Hilsa	169
Range of migration of Hilsa in the Narbada	170
Lunar periodicity in the Hilsa Fishery	171
Ovarian Eggs of Hilsa	171
Eggs and Embryonic development	173
Larval development of Hilsa	174
Acknowledgment	176
List of References	176

INTRODUCTION.

Interest in the life history of Hilsa was first aroused by the preliminary investigations of Francis Day (1873) and by the recommendation of K. G. Gupta (1908). Later on, the Fisheries Departments of Bengal and Bihar and Orissa, and Madras also undertook more detailed investigations on the subject, including artificial fertilization of the eggs. In Bengal, the eggs could not be reared into larvae on account of large quantities of mud held in suspension in the river water and fungus attacks (Southwell and Prashad, 1918), whereas Sundara Raj (1917) records hatching of Hilsa eggs by Wilson as well as by himself. Devanesen (1939) also asserts that the collection and hatching of Hilsa eggs continue as a routine at Madras. It is unfortunate, however, that despite these statements, no detailed description of the eggs and early larvae of Hilsa has ever been published. Nair (1939) described a series of early stages of Hilsa, but the youngest stage described by him is 14 mm., the earlier life history of the fish being yet unknown.

The existence of this lacuna in our knowledge induced the writer to obtain precise data on the nature of the eggs, larvae and breeding habits of this important food fish. Accordingly, eggs were collected in plankton nets from the Narbada river which flows into the Gulf of Cambay on the west coast of India. A few eggs and larvae were obtained in this way, but their identity was not certain. Attempts were, therefore, made to strip ripe fish and to fertilize the eggs artificially in order to determine the identity of the eggs collected in the plankton. A comparison of these eggs with those taken from plankton has not only confirmed their identity but has also strengthened belief in the correctness of the hypothesis advanced by Hora (1938) regarding the spawning grounds of Hilsa. Results of these operations have been detailed in the following pages.

SPAWNING GROUNDS OF HILSA.

Investigations made by Hora (1938) have indicated that the spawning grounds of Hilsa in Bengal are located in the river Hooghly in the neighbourhood of the Pulta waterworks near Calcutta. Hora's findings were based on the occurrence of

Hilsa in the tanks of the municipal waterworks at Pulta. The present observations, on the other hand, are based on the occurrence of fertilized eggs as well as gravid females with oozing eggs in a particular stretch of the river Narbada. Moses (1942) records that in the Narbada, Hilsa are found in its lower reaches during the monsoon months, but he does not state anything regarding their spawning migrations. Investigations were, therefore, undertaken in that river, near the villages of Nicora and Jhanor, about 40 miles up-stream from the sea along the course of the river (*vide* map) and about 12 to 15 miles east of the town of Broach, 200 miles north of Bombay. This area is slightly under the tidal effect, though the water of the river here is entirely fresh (sweet) at all times of the year. The water level of the river rises by about a foot during the highest spring tide.

Inspection of the catches in this area, during July 1949, revealed that some of the gravid females had reached such stage of ripening of their gonads that the eggs were oozing out of the vent. This indicated that they had almost reached their desired breeding grounds and that they would have actually spawned within a short time. Some of these fish were caught in small hand nets, locally known as 'Jamda' nets, and others in ordinary gill nets.

The occurrence of such ripe females (with oozing eggs) in this area may be a satisfactory proof to regard the locality as a spawning ground, but this inference cannot be taken as finally conclusive. A search for fertilized eggs in the water of the river in the same area was, therefore, undertaken. On August 22, 1949, plankton was collected in the five-mile stretch of the river between Nicora and Jhanor with an ordinary tow net with double mosquito curtain netting. In the four hauls which were made, each of 20 minutes duration, no eggs were found in the first two, but, in the last two hauls 75 eggs were collected. Out of these, 25 were dead and unfertilized and the rest were fertilized and of normal shape and size as could be made out from the eggs which were stripped and fertilized artificially on a previous occasion. The eggs were carefully isolated from a large amount of floating debris and hatched in large petre dishes by changing the water at regular intervals and keeping the eggs free from mud particles suspended in the river water. The collection of the eggs was made between the hours of 7 and 8 p.m. when the area was under tidal influence and the temperature of the water was 27.5°C., the river being at its normal flood level.

The occurrence of females with oozing eggs and the presence of fertilized eggs in the plankton indicate beyond any doubt that this area is part of the spawning grounds of Hilsa; detailed observations are, however, necessary to ascertain the extent of these spawning grounds. Further, as stated before, the females with oozing eggs were caught in hand nets, the 'Jamda', operated at a depth of about 3 or 4 feet from the surface. A few were caught in gill nets fixed at about 15 feet below the surface and almost near the bottom. It would appear from this that the ripe females do not necessarily swim at lower depth but can be found travelling very close to the surface also.

RANGE OF MIGRATION OF HILSA IN THE NARBADA.

Hilsa is known to ascend hundreds of miles, in large schools, into rivers, such as, the Ganges, the Indus, etc., but its migration in the Narbada, according to the present investigations, is limited to about 80 miles only from the sea. Observations made along the course of the river have shown that there is hardly any large-scale Hilsa fishing in the river a few miles above the village of Jhanor (40 miles from the sea), as the shoals do not seem to ascend beyond this area. Nevertheless, smaller schools are known to ascend another 40 miles or so up to the village of Garudeshwar (*vide* map). Beyond this village, the river bed is rocky and steep and consequently the current is much stronger. The high velocity of the river current may probably be the main factor that restricts the range of migration of Hilsa in this river. Deter-

mination of velocity at this point would have yielded important data on the swimming powers of the fish in regard to the construction of fish passes in the dams and weirs obstructing upward migration of Hilsa, but the work could not be accomplished during the last season.

It is reported that Hilsa is not known to ascend higher than about five miles in the Purna river on the Gujarat coast. Similarly, in the Ulhas river, north of Bombay, it is known to ascend only about 25 miles. It is thus of interest to note that while the fish travels very long distances in the Ganges, the Indus, etc., its migration to rivers on the western coast is very much limited. Further investigations may reveal precise reasons for this restricted migration and may indicate the possible means of solving the problems arising from restriction of range of migration of this important fish due to the construction of dams across some of the large rivers of India. One important fact which emerges from these observations is that Hilsa is capable of adapting itself to variable environments and of breeding even within 50 miles from the sea, depending on several factors, such as, the strength of the current, salinity, volume, depth of water, etc.

LUNAR PERIODICITY IN THE HILSA FISHERY.

Majumdar (1939) recorded that Hilsa fishing is done in the Sundarbans during the neap tide. It is reported that on the Balasore coast Hilsa fishing is done from the 11th day of the moon till the 3rd day after the full moon, i.e., during the spring tide and again during ebb tide from the 11th day after the full moon (Prashad, Hora and Nair, 1940). A similar lunar periodicity has also been observed in the Narbada, where Hilsa fishing is done from the 12th day of the moon to the first day after the full moon or the new moon in each lunar fortnight. Thus, the fishing is done only during the two spring tide periods in each month. The catches during the neap tide period are so low that practically all fishing is suspended during this period. From the observations made at most of the fishing villages along the Narbada, as well as from the experience of coastal and estuarine fishing of a general nature, it seems that the 'neap tide' mentioned by Majumdar (*Loc. cit.*) and the 'ebb tide from the 11th day after the full moon' reported by Prashad *et al.* (*Loc. cit.*) may be language errors. The reporters probably had in mind only the spring tide periods commencing from the 11th day of the moon in the second fortnight of the lunar month. The matter would, however, require additional data from the same places to settle this point.

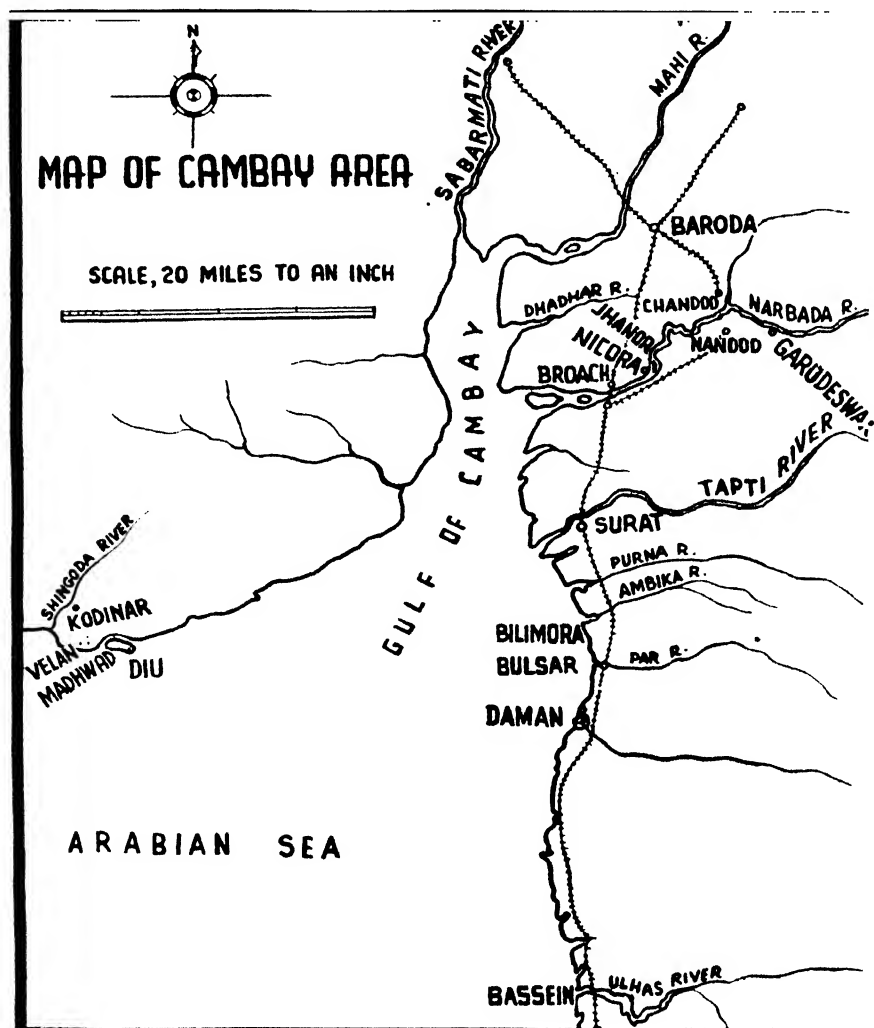
The analysis of the catches of the fishermen made at Jhanor and Nicora showed that the proportion of ripe females (oozing eggs) is very small and that such ripe fish are usually caught during the high tides. Catches of 25 fishermen were examined on July 22 and 23 (13th and 14th days of the moon) and again on August 7 and 8 (12th and 13th days of the moon). Out of the total catch of 350 fish examined in July there were 6 ripe females, whereas in the catch of 3,000 fish caught in August, 70 ripe females were recorded. Their number on other days was much smaller. This would indicate that during spring tide the mature fish ascend the river in larger numbers for spawning and there is thus a lunar periodicity in the reproduction of this fish. The fact that fertilized eggs were obtained in the plankton collected on the 14th day of the moon (August 22, 1949) also lends support to this view.

OVARIAN EGGS OF HILSA.

Clupeoid fishes, of which Hilsa is a member, are known for the large number of ova they produce, but precise information regarding Hilsa is lacking.* Hilsa has

* Since writing this, Chacko and Ganapati, *Journ. Madras Univ.*, XVIII, 1949, estimated 1,282,110 eggs in *H. ilisha*.

a bilobed ovary which grows and fills the entire body cavity when fully developed. The weight of such a gonad in a large female 512 mm. in total length (437 mm. standard length) and 4.5 lb. in weight, is 13.7 oz. A part of this roe along with its mesenteries was cut, weighed and the number of ova counted. This showed that the ovary contained about 1,864,000 ova. All these ova are almost in the same stage of development and appear to be intended for a single spawning season. If a small piece of ovary is teased out and examined under a microscope, it will be apparent that along with the aforesaid developed ova there is also another category of very small undeveloped ova (Text-fig. 2a) attached to the mesenteries which appear to be intended for the next season. Each developed ovum is roughly 1 mm. in diameter, but all of them being held together in a compact mass in the ovary, are not

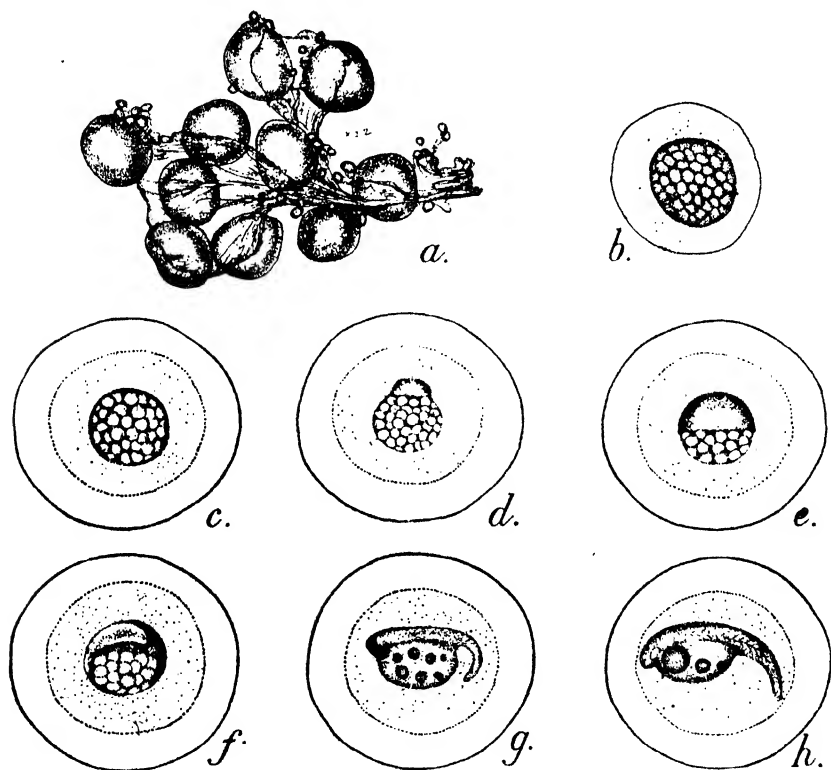


TEXT-FIG. 1.—Map to show the rivers discharging into the Gulf of Cambay.

completely round or spherical until they ripen and are ready to be shed. The yolk of the ova is opaque at this stage and the compact mass of the ovary can be said to be comparatively hard (hard roe). However, when the ova ripen, the yolk becomes more or less fluid and transparent and the eggs become soft. They then get disentangled from the mesenteries and flow out through the genital aperture even on a very slight pressure on the abdomen. Such ripe, unfertilized eggs are almost spherical and their diameter is about 1.3 mm. (Text-fig. 2b).

EGGS AND EMBRYONIC DEVELOPMENT.

On July 22nd, 1949, one ripe female caught in a hand net was stripped in an enamel dish and the eggs were immediately fertilized artificially with the milt obtained from a freshly caught male. The eggs were very soft and smooth and appeared to be pale dirty brownish in colour. When freshly laid, they are 1.3 to 1.5 mm. in dia. with semi-fluid vitelline material (Text-fig. 2b). On immersion in water, the eggs begin to absorb water till they are 2.1 to 2.3 mm. in dia. (Text-fig. 2c). At this stage they are demersal in still water, but their density is so close to that of the water, that even with a slight current, they keep on drifting and appear pelagic



TEXT-FIG. 2.—Eggs and Embryonic Development of *Hilsa ilisha* (Ham.)

a. Piece of an ovary showing fully developed and undeveloped ova along with mesentery $\times 11$; b. A ripe unfertilized ovum $\times 13$; c. A fertilized egg after absorption of water $\times 13$; d. Blastodisc formation after $\frac{1}{2}$ hour of fertilization $\times 13\frac{1}{2}$; e. A stage 4 hours later $\times 13\frac{1}{2}$; f. Formation of embryonic shield after 8 hours $\times 13\frac{1}{2}$; g. An embryo formation 12 hours later $\times 13\frac{1}{2}$; h. 17 hours later embryo ready to escape from the egg $\times 13\frac{1}{2}$.

in nature. The egg membrane, when distended with absorbed water, appears smooth and devoid of any processes or corrugation. Inside this outer membrane, there is another very thin and delicate inner membrane. Thus the egg membrane of Hilsa is double-layered as in the English herring (McIntosh and Masterman, p. 410). These two membranes, according to Hoffman (as quoted by McIntosh and Masterman, *op. cit.*) form the zona radiata of the egg. The water absorbed and stored in the perivitelline space serves as a very useful cushioning for the delicate embryo growing over the yolk. The yolk appears to be composed of a number of small oil globules which form a large conglomeration in the centre of the egg. This gives the appearance of segmented yolk which is considered by Delsman (1926) as characteristic of all clupeoid eggs.

The development of the egg starts immediately after fertilization. Within half an hour, the streaming movement of the protoplasm towards the lower pole is completed and a blasto-disc is formed (Text-fig. 2d). Segmentation of the blasto-disc takes place quite rapidly and within the following four hours a cap of cells covering up to about half the conglomerate oil globule is developed (Text-fig. 2e). After another four hours, an embryonic shield is visible (Text-fig. 2f). Development at this stage appeared to be quite rapid and after twelve hours a distinct embryo with a prominent protrusion representing the head still attached to the yolk sac and a tail free from the sac (Text-fig. 2g) is visible. A few muscle segments can be made out, but the formation of the optic vesicle is not discernible. Contractions of the body of the embryo begin after about 15 hours and they become more frequent after another two hours. These contractions help to coalesce the small oil globules into larger and fewer ones reducing them finally to three or four. After 17 hours, the embryo becomes restless within the egg membrane. Its struggle indicated that it was attempting to escape from the egg membrane and appeared to exert pressure on it with its head and tail (Text-fig. 2h). This struggle was continued for some time with an intermittent period of rest. After full 18 hours, the larva burst out of the egg membrane and swam out vigorously vibrating its tail. The temperature of the river water was 28°C. and that of the water in which the eggs hatched out was 28.5°C., there being some slight fluctuation when the water of 27.5°C. cooled in earthen pots was being added. All eggs do not necessarily hatch out after 18 hours but require different periods ranging up to 26 hours, the period depending probably on the temperature, oxygenation of the water, etc.

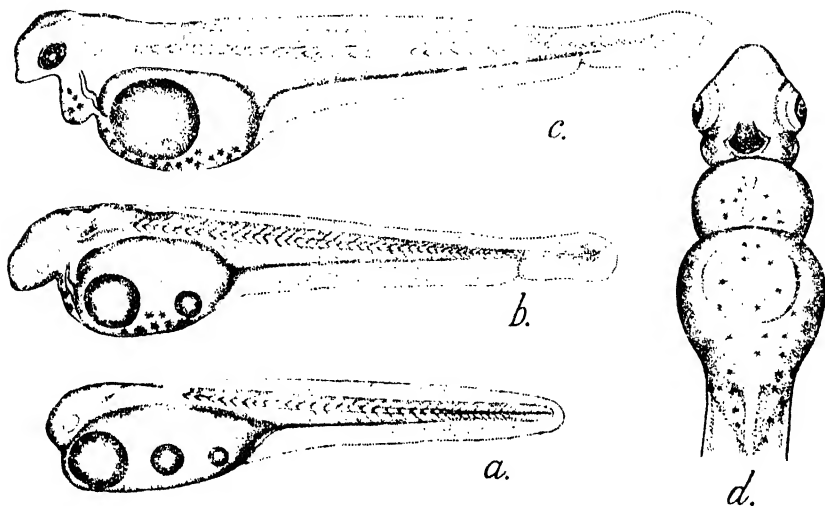
LARVAL DEVELOPMENT OF HILSA.

Newly hatched Larva: As compared to the size of the egg, the first hatchling or the earliest larva of Hilsa is very small, being only 3.1 mm. in total length (Text-fig. 3a). The head seems to be yet in contact with yolk sac and the optic vesicles, though fully developed, are indistinct and do not have any pigment in them. Auditory capsule is not yet visible. The yolk sac is large and oblong and is attached to the body along its longer axis. There are three distinct oil globules, the anterior-most is the largest and the remaining two being smaller. In some cases there is a fourth oil globule also. There is a very thin and narrow vertical fin fold which is continuous over the caudal end but it is not differentiated into a caudal lobe. In the living condition the larva is almost transparent and is visible only with difficulty.

As soon as the larva hatches out from the egg it swims violently up to the surface of the water by vibrating its tail and then drops down listlessly on to the bottom for a while. This peculiar movement is repeated intermittently. During these sporadic movements, the larva does not swim in the normal position, but on account of the buoyancy of the yolk and the large oil globules, it swims upside down and rests on the bottom on its dorsal side.

Second day Larva: The larva on the second day (Text-fig. 3b) grows to a total length of 3.7 mm. The head portion seems to be further developed and hangs out

prominently and is unattached to the yolk sac. A tubular heart is also visible between the head and the yolk sac on the ventral side. On closer observation, the heart can be seen pulsating rhythmically but no red blood corpuscles could be seen. The eyes have developed but yet there is no pigment. Auditory vesicles are visible. The yolk sac is slightly reduced in size but instead of three oil globules only two are now present. About 42 muscle segments are clearly visible and the rest are indistinct. The anus appears at about 38th segment from the head. The fin membrane is well-formed and the caudal lobe is being differentiated. Very small black chromatophores are present on the throat as well as on the yolk sac but the body is devoid of any such pigment.



TEXT-FIG. 3.—Larval Development of *Hilsa ilisha* (Ham.) $\times 22$.

a. Hatchling of Hilsa; b. Larva on the 2nd day; c. Larva on the 3rd day; d. Ventral view of the anterior part of the larva on the 3rd day.

Although the larva has progressed considerably on the second day, it still swims upside down and rests on the dorsal side as on the previous day. Unlike the first day stage, it does not, however, come to the surface of the water and drop down but swims at intervals on the bottom only.

Three-day-larva: On the third day, the larva (Text-fig. 3c) does not seem to increase much in size being only 4.2 mm. in length, but further internal growth seems to have advanced well. The striking feature in the head region is the development of black pigment in the eyes which look quite prominent. Another characteristic feature is that the red blood corpuscles are seen coursing through the tubular pulsating heart. In the ventral aspect (Text-fig. 3d) a distinct mouth is apparent which looks like a comparatively large orifice with only the lower or hind lip. The fin membrane is slightly modified in the dorsal region and looks slightly higher in the region of the dorsal fin. The caudal lobe is further differentiated and the dorsal lobe more developed. The anus is distinct and the development of the intestine also is discernible. The position of the anus indicates that it has migrated anteriorly during the course of the day, on the same lines as has been observed by Nair (1939) in later stages of the fish.

In its movements, the larva does not yet assume the normal position but continues to swim in an inverted posture as before. However, while resting on the

bottom, it rests on the side and this development indicates the possibility of the larva assuming its normal position on the fourth day.

Further observations on the larval development were, however, cut short as the larva died of metallic poisoning as a result of the accidental use of water stored in a copper pot.

ACKNOWLEDGMENT.

The author is deeply indebted to Dr. S. L. Hora, Director, Zoological Survey of India, for his very valuable help in the preparation of this paper.

LIST OF REFERENCES.

- Day, F. (1873). Report on the Fresh Water Fish and Fisheries of India and Burma, 22, 23, 35, 36.
 Delsman, H. C. (1926). Fish eggs and larvae from the Java Sea. *Trenbia*, 8, 220.
 Devanesen, D. W. (1939). Research work on Hilsa. *Curr. Sci.*, 8, 126.
 Gupta, K. G. (1908). Report on the result of Inquiry into the Fisheries of Bengal, etc., 92.
 Hora, S. L. (1938). A Preliminary Note on the Spawning Grounds and Bionomics of the so-called Indian Shad, *Hilsa ilisha* (Hamilton) in the River Ganges. *Rec. Ind. Mus.*, 40, 147-158.
 McIntosh, W. C. and Masterman, A. T. (1892). The life histories of British Marine Food Fishes, London.
 Mojumdar, C. H. (1938). Foreshore Fishing in the Eastern Part of the Bay of Bengal. *Sci. & Cult.*, 5, 219-221.
 Moses, S. T. (1942). The Fisheries of the Gujarat Coast. *Journ. Guj. Res. Soc.*, 4, 61-82.
 Nair, K. K. (1939). On some early stages in the Development of the so-called Indian Shad, *Hilsa ilisha* (Hamilton). *Rec. Ind. Mus.*, 41, 409-418.
 Prashad, B., Hora, S. L. and Nair, K. K. (1940). Observations on the Sea-ward Migration of *Hilsa ilisha* (Hamilton). *Rec. Ind. Mus.*, 41, 409-418.
 Sundara Raj, B. (1917). On the Habits of the Hilsa (*Clupea ilisha*) and their artificial propagation in the Coleroon. *Journ. Proc. Asiat. Soc. Bengal (N.S.)*, 13, clxxxiv.
 Southwell, T. and Prashad, B. (1918). On Hilsa investigations in Bengal, Bihar and Orissa. *Bull. Dept. Fish. Bengal, Bihar and Orissa*, 11.

STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION.

PART III.

The effect of Progesterone and Desoxycorticosterone Acetate on the Distribution and Concentration of Alkaline Phosphatase in the genital System of female Pigeons.

By AMIYA B. KAR, M.Sc., Ph.D. (Edin.), Central Drugs and Pharmacognosy Laboratories, Government of India, Calcutta.*

(Communicated by Dr. B. Mukerji, F.N.I.)

(Received March 13, 1950.)

INTRODUCTION.

The distribution and concentration of alkaline phosphatase has been studied cytochemically in the ovary of several species of mammals and in the pigeon. In the pig, the dog, and in the human the thecal cells contain abundant phosphatase but those of the granulosa contain none (Corner, 1948). The condition is reversed in the rabbit while in the rhesus monkey the enzyme is present in both the layers (Corner, 1944 and 1948). Alkaline phosphatase is demonstrable in the graafian follicles, corpora lutea, interstitial tissue, and in the blood vessels of the rat's ovary (Dempsey *et al.*, 1949). The enzyme disappears from the ovary of hypophysectomized rats but replacement therapy with pituitary powder causes a reappearance of the enzyme and a return to a condition approximating that of the normal gland. In the ovary of the pigeon alkaline phosphatase is present in the theca, blood vessels, and in the stromal tissue (Kar, 1950 a). Androgenic treatment causes a spectacular mobilization of the enzyme in the theca.

Experimental studies in the mouse have shown that estrogen treatment causes an increase in the uterine phosphatase. Progesterone and androgen do not have this effect (Atkinson and Elftman, 1946 and 1947). Karnell and Atkinson (1948) have found only negligible quantities of alkaline phosphatase in the vaginal epithelium of the ovariectomized mice: Estrogen therapy in such animals results in a marked increase in the vaginal phosphatase activity. In ovariectomized rhesus monkeys pre-treated with estrogen, the enzyme is found chiefly in the endometrial glands and in the surface epithelium (Atkinson and Engle, 1947). Progesterone treatment causes considerable reduction of phosphatase in the surface epithelium of these monkeys. The enzyme disappears completely from the vagina of rats after ovariectomy but is increased in the uterine horns (Thibault and Soullairac, 1948). Estrogen therapy re-establishes a normal phosphatase activity in the vagina but the normal enzyme conditions are restored in the uterine horns only if progesterone is administered following estrogen therapy. Dempsey *et al.* (1949) described the disappearance of phosphatase from the uterus of the rat after hypophysectomy and its restoration on replacement therapy with estrogen or pituitary powder. In the oviduct of juvenile pigeons there is practically no phosphatase, but in the birds of the same age treated with estrogen, the phosphatase concentration is markedly increased in the hypertrophied oviduct (Kar, 1950 b). Androgen treatment,

* Senior Research Fellow, National Institute of Sciences of India.

however, is less effective in augmenting the amount of oviducal phosphatase in the pigeon.

The present report has been concerned with an attempt to study the effect of progesterone and desoxycorticosterone acetate on the distribution and concentration of alkaline phosphatase in the genital system of female pigeons.

EXPERIMENTAL.

Female pigeons, 110 days old were used in this study. A total of 15 birds were involved of which 5 were injected with progesterone, 5 with DCA, and the remaining 5 were left uninjected to serve as the controls. The birds were kept in cages under uniform husbandry conditions throughout the duration of the experimental period.

Progesterone in sterile sesame oil was administered intramuscularly. The daily injections (0.1 mg.) were made into the breast muscles and continued for a period of 24 days. An equal amount of DCA (0.1 mg. in sterile sesame oil) was injected in the similar manner and over the same period of time. The sites of injection alternated on successive days between the right and left sides of the breast.

Autopsy followed 24 hours after the final injections. The ovary and the oviduct were fixed immediately in chilled 80% ethyl alcohol and in Bouin's fluid. After dehydration and imbedding in paraffin, serial sections were cut 6 microns in thickness. The tissues fixed in Bouin's fluid were stained with Mallory's trichrome stain. The sections of the ovary and the oviduct fixed in ethyl alcohol were incubated in sodium glycerophosphate substrate (pH 9.5) according to the technique of Gomori (1941) for the demonstration of alkaline phosphatase. The sites of phosphatase activity in the tissue sections are marked by the deposition of cobalt sulfide in fine black granules. In order to allow critical observation of these deposits no counter-stain was used. The sections were dehydrated and mounted in the usual manner.

RESULTS.

A. Controls.

Ovary. There is very little phosphatase in the granulosa cells of the ovary. The endothelium of the thecal blood vessels shows strong reactions for the enzyme. Moderate amounts of phosphatase are present in the nucleus of the thecal cells but the cytoplasm of these cells contains only a trace of the enzyme. The phosphatase activity is evident in the endothelium of the stromal blood vessels and in the connective tissue cells but the interstitial cells show negative reactions for the enzyme (Pl. VII, fig. 1).

Oviduct. No phosphatase activity is visible in either the serosa or in the muscularis. The epithelium bordering the mucosal folds and the connective tissue stroma, however, show the presence of small amounts of phosphatase. The maximum concentration of the enzyme is seen in the young tubular glands of the oviduct (Pl. VII, fig. 2).

B. Progesterone treatment.

Ovary. The inhibition of the ovarian growth similar to that reported by Kar (1949) following progesterone treatment is also observed in the present material. The suppression of the follicular development due to the luteoid treatment is evident upon microscopical examination. There is no trace of phosphatase in the granulosa or in the thecal region (Pl. VII, fig. 3). Small amounts of the enzyme are present in the connective tissue cells and in the endothelium of the stromal blood vessels. Interstitial cells, however, continue to give a negative reaction for the phosphatase.

Oviduct. The consequences of the luteoid-induced ovarian inhibition is clearly reflected in the marked hypoplasia of the oviduct. Histological examination discloses an immature condition of the duct with low and non-glandular mucosal

folds. The sub-mucus region presents the appearance of a thin connective tissue lamina and the muscularis appears as an extremely thin peripheral layer. Test for alkaline phosphatase is entirely negative in the component parts of the oviduct (Pl. VII, fig. 4).

C. *Desoxycorticosterone acetate treatment.*

Ovary. The ovary shows signs of hypertrophy. These are evidenced by somewhat accelerated development of the follicles and the stromal growth. The enzyme is practically absent in the granulosa. There is, however, a spectacular mobilization of phosphatase in the theca (Pl. VII, fig. 5). The nucleus and the cytoplasm of the thecal cells as well as the endothelium of the thecal blood vessels show high concentration of alkaline phosphatase. Only small amounts of the enzyme are present in the stromal connective tissue cells and in the endothelium of the blood vessels. The interstitial cells are prominent by the absence of the enzyme.

Oviduct. The oviduct shows induced growth in the serosa, muscularis, and in the mucosal folds. There is, however, no glandular development. The enzyme is absent from the component parts of the oviduct, except the stroma and the mucosal epithelium where only small amounts are present (Pl. VII, fig. 6).

DISCUSSION.

A number of recent studies have revealed a relationship between the endocrine status and the activity of the selected enzymes (*vide* Dempsey *et al.*, 1949). These studies have clearly indicated the possibility that the relationship between the hormones and the enzymes has a causal significance. Moreover, a series of investigations have proved beyond doubt that the activity of the phosphatases vary under different physiological conditions (Dempsey *et al.*, 1949; Karnell and Atkinson, 1948; Atkinson and Engle, 1947; Thibault and Saulsairac, 1948; Kar, 1950, *a, b* and *c*; and others). In view of this, it is not surprising that the ovarian phosphatase activity in the pigeon should change after hormonal treatments. Thus, progesterone administration in the female pigeon is known to cause inhibition of the ovarian growth and the suppression of the follicular development (Kar, 1949). Concomitantly, the phosphatase activity is considerably diminished in the stroma and totally disappears from the ovarian theca of the luteoid-treated birds. DCA treatment, on the other hand, causes a spectacular mobilization of the enzyme in the theca of a somewhat hypertrophied ovary. It is interesting to note that testosterone propionate also causes a similar mobilization of alkaline phosphatase in the ovarian theca of the pigeon (Kar, 1950 *a*). The action of DCA on the phosphatase activity in the pigeon's ovary, therefore, appears to be androgenic.

The consequence of the loss of phosphatase activity in the ovary of progesterone-treated birds is unmistakably reflected in the change that ensued in the oviduct. This is clearly evident from the total absence of the enzyme from the component parts of the duct. However, a different picture is presented if we reckon the effects of DCA administration. Histologically, there is induced growth in the serosa, muscularis, and in the mucosal folds, but there is no functional development, which can be gauged from the fact that the tubular glands are absent from the mucosa. Cytochemically, only small amounts of phosphatase are present in the oviduct. Here again, the situation is comparable to a similar one that is encountered in the pigeon's oviduct after testosterone propionate treatment. Induced growth of the duct except however, the development of the tubular glands are the noteworthy histological alterations, while cytochemically, there is little augmentation of enzymatic concentration (Kar, 1950 *b*), although the ovary shows a marked increase in phosphatase activity (Kar, 1950 *a*). The findings on the oviduct of the DCA-treated pigeons, therefore, appear to extend the observations made on the ovary and indicate that the corticoid is undoubtedly androgenic in influencing the

distribution and concentration of alkaline phosphatase in the genital system of female pigeons.

SUMMARY.

Intramuscular injections of progesterone ensues a loss of alkaline phosphatase activity in the genital system of female pigeons. Desoxycorticosterone acetate treatment, however, causes a spectacular mobilization of the enzyme in the ovarian theca but there is little augmentation of phosphatase activity in the oviduct. The similarity between the corticoid and testosterone propionate in influencing the enzymatic activity in the genital system of the pigeon is pointed out and discussed.

ACKNOWLEDGMENTS.

The author wishes to express his gratitude to Dr. B. Mukerji, Director, Central Drugs and Pharmacognosy Laboratories, for constant help and encouragement. Grateful acknowledgment is made to Dr. K. H. Gruschwitz of Ciba Pharma, Ltd., Calcutta, for the generous contribution of progesterone (Lutocyclin) and desoxycorticosterone acetate (Percorten) used in this study. Thanks are due to Sri P. C. Pathak for taking the photomicrographs which illustrate this paper.

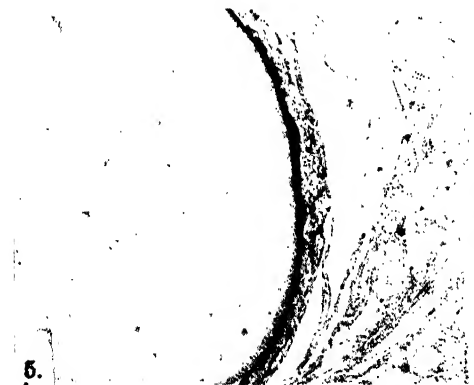
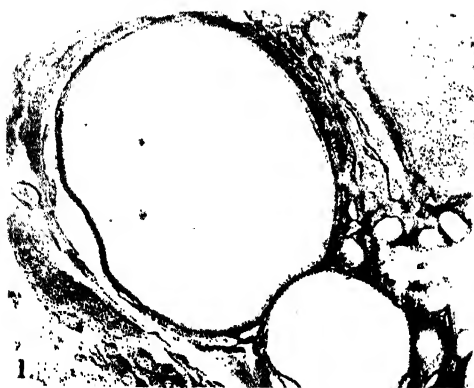
REFERENCES.

- Atkinson, W. B. and H. Elftman (1946). Effect of steroid sex hormones on distribution of alkaline phosphatase in uterus of mouse. *Proc. Soc. Exp. Biol. and Med.*, **62**, 148-150.
- (1947). Mobilization of alkaline phosphatase in the uterus of mouse by estrogen. *Endocrinol.*, **40**, 30-38.
- Atkinson, W. B. and Engle, E. T. (1947). Studies in endometrial alkaline phosphatase during the human menstrual cycle and in the hormone treated monkey. *Endocrinol.*, **40**, 327-333.
- Corner, G. M. (1944). Alkaline phosphatase in the ovarian follicles and corpora lutea. *Science*, **100**, 270-271.
- (1948). Alkaline phosphatase in the ovarian follicles and in corpus luteum. *Contrib. Embryol. Carnegie Inst. of Washington*, **32**, 1-8.
- Dempsey, E. W., Greep, R. O. and Deane, H. W. (1949). Changes in the distribution and concentration of alkaline phosphatase in the tissues of the rat after hypophysectomy, and after replacement therapy. *Endocrinol.*, **44**, 88-103.
- Gomori, G. (1941). The distribution of alkaline phosphatase in normal organs and tissues. *J. Cell. and Comp. Physiol.*, **17**, 71-83.
- Kar, A. B. (1949). The action of progesterone on the female genital system of juvenile pigeons. *Ind. J. Physiol. and Allied Sci.*, **3**, 16-20.
- (1950 a). Studies on cytochemistry of hormone action—Parts I and II. *Proc. Nat. Inst. Sci. Ind.*, **16**, 41-45.
- (1950 b). Studies on oviducal alkaline phosphatase in normal and in sex hormone treated pigeons. *Abstract: Proc. Ind. Sci. Congr., 37th Session, Poona*, 803-804. (Full paper will appear in this journal.)
- Kar, A. B. (1950 c). Studies in the distribution and concentration of alkaline phosphatase in the adrenal cortex of normal and of sex hormone treated pigeons. *Endocrinol.*, (in press).
- Karnell, S. A. and Atkinson, W. B. (1948). Effects of ovarian hormones on certain cytoplasmic reactions in the vaginal epithelium. *Proc. Soc. Exp. Biol. and Med.*, **68**, 537-540.
- Thibault, C. and Soulaire, A. (1948). L'activité phosphatasique du tractus génital des mammifères. Modifications expérimentales chez le rat femelle. *Ann. Endocrinol.*, **9**, 555-557.

EXPLANATION OF PLATE VII.

(All figures are photomicrographs and are magnified $\times 200$.)

- FIG. 1.—Section through the ovary of an untreated pigeon. Note the distribution of alkaline phosphatase.
- FIG. 2.—Section through the oviduct of an untreated pigeon. Phosphatase is present in the tubular glands.
- FIG. 3.—Section through the ovary of a progesterone-treated pigeon. Compare with fig. 1.
- FIG. 4.—Section through the oviduct of a progesterone-treated pigeon. Phosphatase is absent.
- FIG. 5.—Section through the ovary of a DCA-treated pigeon. Note the spectacular mobilization of alkaline phosphatase in the theca.
- FIG. 6.—Section through the oviduct of a DCA-treated pigeon. Compare with figs. 2 and 4.



(For explanation of plate, see p. 180.)

ON THE LARVAL DEVELOPMENT OF THE INDIAN TRANSPARENT GOBY, *GOBIOPTERUS CHUNO* (HAMILTON) WITH OBSERVATIONS ON ITS BIONOMICS.

By T. V. R. PILLAY, *I.C.I. Research Fellow, N.I.S.I., Zoological Survey of India
Laboratories, Calcutta,*

and

K. K. SAROJINI, *Asst. Research Officer (Estuarine), Central Inland Fisheries Research
Station, Barrackpore.*

(Communicated by Dr. S. L. Hora, D.Sc.)

(Received March 9, 1950.)

CONTENTS.

	<i>Page</i>
Introduction	181
Breeding Season and Fecundity	181
Ovary and Ovarian Eggs	182
Larval Development	182
Significance of the developmental features	185
Bionomics	185
Summary	186
Acknowledgments	187
References	187

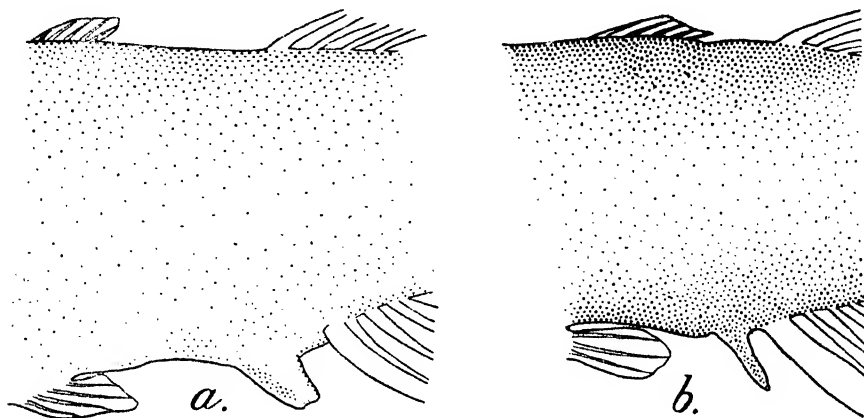
INTRODUCTION.

The larval development of the European Transparent Gobies, *Aphyia pellucidus* Nardo, and *Crystallogobius nilsoni* V. Dub & Kor, has been described by Lebour (1919), but nothing was so far known about the breeding and development of the Indian form, *Gobiopterus chuno* (Hamilton). During regular collections of mullet fry, the larvae of this fish were secured in the plankton net from a brackish water-pool in Baguranjalpai, a coastal village in Contai (W. Bengal), during the months of October and November. This pool is situated near the farthest end of a narrow creek. During the spring tides the pool gets connected with the main creek, but otherwise remains isolated. At the time of the collections referred to above, the pool had thus been cut off, for over a week. The collections contained numerous mature 'Chuno', many of which were in the oozing condition.

BREEDING SEASON AND FECUNDITY.

Adult 'Chuno' were observed to be present in the collections from this area, from June onwards. A few mature specimens were obtained in August, but they occurred in appreciable numbers only from September to December. The larvae were collected during October and November, and it may be inferred that they breed in the locality at least from October to December. Mature females have the abdomens greatly distended with eggs, which are quite visible through the body wall. The adults of the species exhibit marked sexual dimorphism. The genital papilla which is present in both the sexes, is stouter and more prominent in the female (Text-fig. 1a) than in the male (Text-fig. 1b). The ripe female has the

conical teeth on the jaws considerably larger than the minute ones found in the male as already described by Hora (1923). In the ovary of a specimen 23 mm. long there were only 276 eggs. All the eggs were nearly of the same size and stage of maturity suggesting that all of them were meant for one spawning. The mature specimens varied from 22 mm. to 24 mm. in length, and in our collections which consisted of more than 900 specimens, there were no mature ones below this size range.



TEXT-FIG. 1. (a) The genital papilla of a female $\times 35$.
(b) The genital papilla of a male $\times 35$.

OVARY AND OVARIAN EGGS.

The two lobes of the ovary are of the same size and shape, and as maturity is attained they swell considerably with the result that they come to lie in close apposition, the whole ovary appearing as a single oval mass. A ripe ovarian egg (Text-fig. 2a) is nearly spherical in shape, and measures 0.425 mm. to 0.5 mm. in diameter. When examined under the microscope, numerous unbranched adhesive threads can be seen radiating from a point on the egg membrane, presumably for attachment to vegetation or other objects in the water. There is a single large oil globule besides several small ones distributed in the yolk.

LARVAL DEVELOPMENT.*

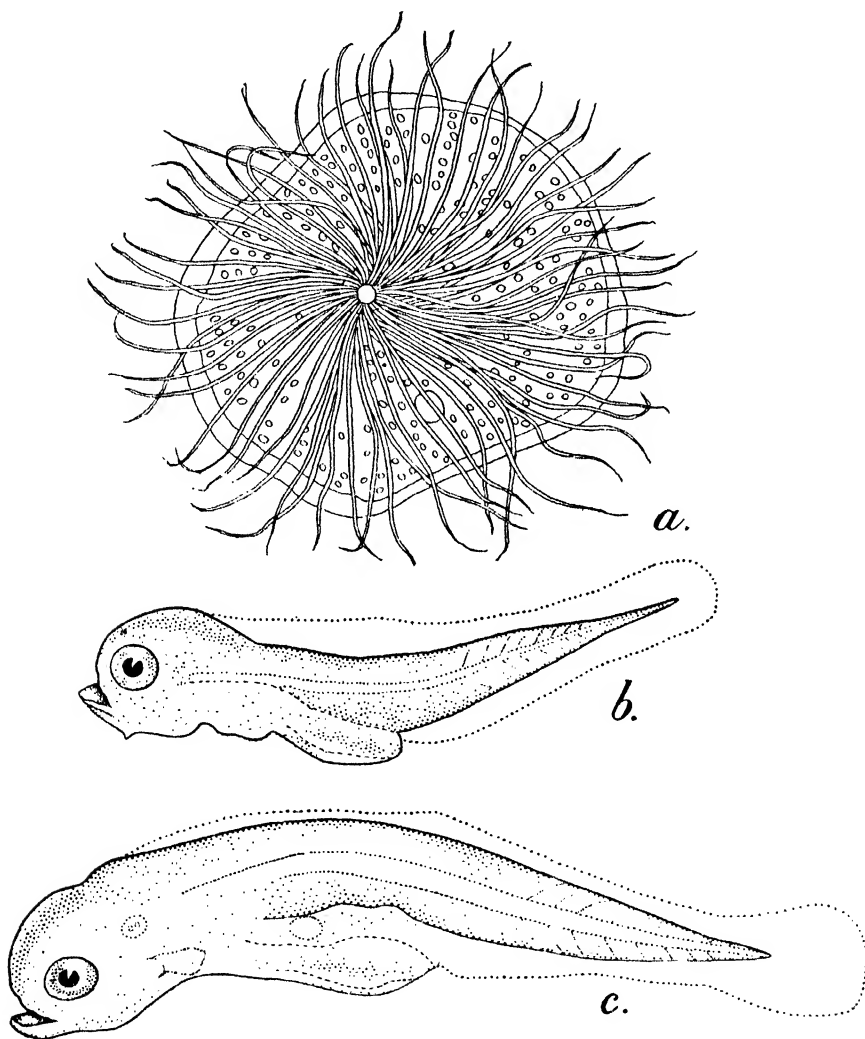
Specimen 1.7 mm. long.—(Text-fig. 2b). This is the earliest stage in our collections. The yolk mass at this stage appears to have been fully absorbed. The mouth is inferior and the alimentary canal is a straight tube. The vent is situated at about the midbody length below the 9th myotome. The eyes are fully pigmented and the auditory capsule is recognizable. The median finfold is continuous and extends dorsally to the head.

Specimen 2.7 mm. long.—(Text-fig. 2c). The body of the larva at this stage has essentially the same shape as the 1.7 mm. larva. The median finfold has become narrow dorsally and the caudal lobe has been demarcated. The pectoral fin is visible at this stage as a transparent membrane. The intestine shows a slight bend. The vent has shifted slightly backwards and is situated below the 11th myotome. The air bladder is conspicuous.

Specimen 3.4 mm. long.—(Text-fig. 3a). At this stage the body appears slightly compressed. The mouth is still inferior in position. The air bladder has become longer and is clearly visible. There is a large pigment spot above the air bladder

* The descriptions and measurements are based on permanent mounts of specimens.

which is characteristic of the gobiid larvae. Dorsally the finfold stops short of the trunk region above the 11th myotome. The soft dorsal and the anal fins are more or less demarcated. The caudal fin has a nearly straight posterior margin.

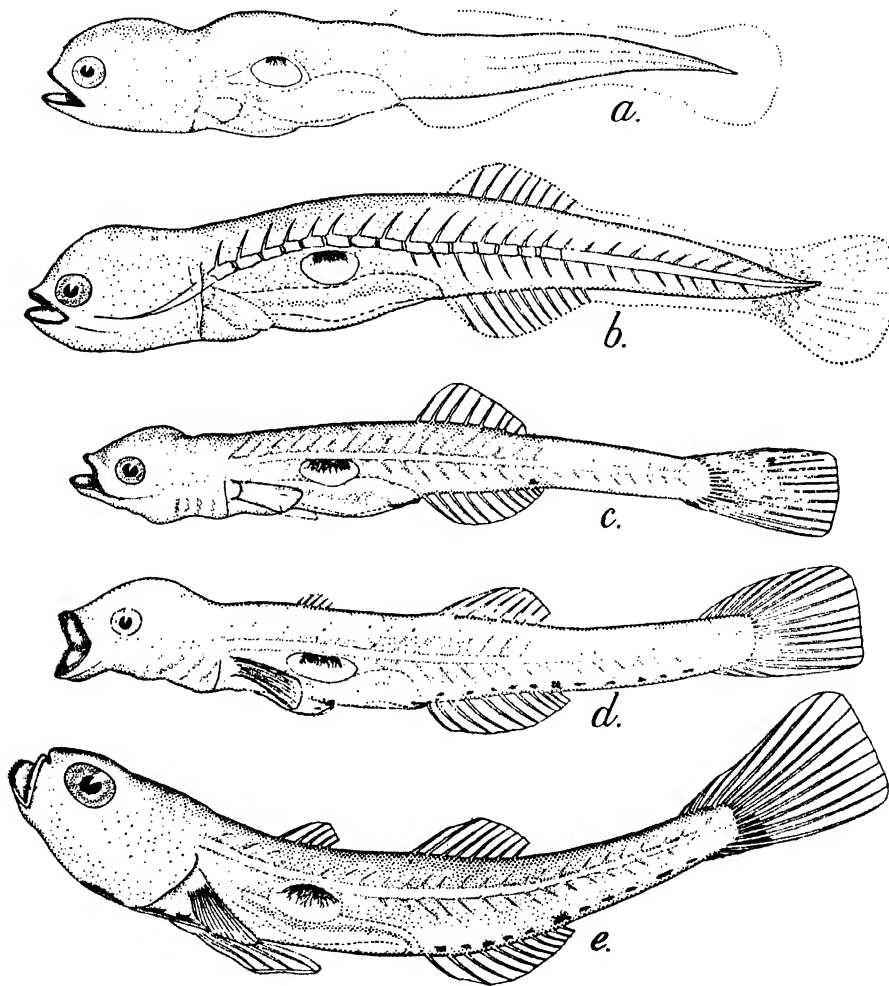


TEXT-FIG. 2. (a) Ovarian egg $\times 150$.
 (b) A 1.7 mm. long specimen $\times 55$.
 (c) A 2.7 mm. long specimen $\times 55$.

Specimen 4.3 mm. long.—(Text-fig. 3b). The body of the larva of this size is well compressed. The mouth is now terminal in position and the dorsal profile of the head is more prominently arched. The pigment spot is very prominent now. The pectorals show indications of rays on them. The notochord shows a slight bend upwards at its tip. In alizarin stained specimens, 10 pre-anal and 15

post-anal vertebral segments can be clearly counted. The soft dorsal and anal fins have their rays fully differentiated. There are indications of rays on the caudal. The spinous dorsal is not yet evident.

Specimen 5.4 mm. long.—(Text-fig. 3c). The body has grown slender, and the caudal peduncle is somewhat constricted and in this region the dorsal and ventral profiles are almost straight and parallel. The tip of the peduncle is no more pointed, but is broad and truncate. The mouth is now slightly superior and oblique. The gill rudiments can be seen through the opercular fold. There is a single chromatophore on either side of the body, situated above the posterior end of the anal fin. The soft dorsal, caudal and anal fins have been separated and are



TEXT-FIG. 3. (a) A 3.4 mm. long specimen $\times 55$.
 (b) A 4.3 mm. long specimen (Alizarin stained) $\times 50$.
 (c) A 5.4 mm. long specimen $\times 35$.
 (d) A 6.3 mm. long specimen $\times 35$.
 (e) A 7.5 mm. long specimen $\times 35$.

fully developed. The pectoral and pelvic fins can be seen as transparent membranes without any rays. There is still no indication of the spinous dorsal. The caudal has assumed the truncate shape of the adult, and all the thirteen rays besides some incomplete ones have been formed.

Specimen 6.3 mm.—(Text-fig. 3d). The body shape is essentially the same as of the 5.4 mm. stage. The mouth is more superior and oblique. Teeth are visible on the jaws. A ventral row of black chromatophores is seen on either side of the body extending from above the anal fin to the tip of the caudal peduncle. Of these the sixth from the anterior end, which was visible in the previous stage is the largest. The spinous dorsal has been formed. The pectorals show indications of rays on them. The pelvics have partially united and begun to develop rays.

Specimen 7.5 mm. long. (Text-fig. 3e). Specimens of this length have almost all the adult characters, except for the absence of scales. The mouth is definitely superior and oblique; and the eyes are situated on the sides. There are two long chromatophores below the chin and a few pigment spots at the base of the caudal.

SIGNIFICANCE OF THE DEVELOPMENTAL FEATURES.

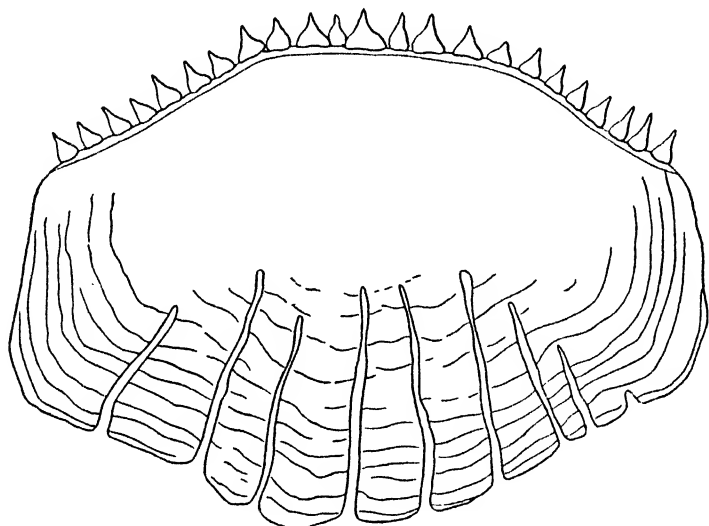
The larval development of the 'Chuno' is remarkably different from that of the common gobiids. Hildebrand and Cable (1938) have stated that generally in gobiid larvae, at hatching 'the mouth tends to be horizontal and inferior, but very soon becomes rather oblique'; and as the adult stage is reached the mouth in at least several species assumes again nearly the position occupied at hatching. The caudal fin when formed has either a straight or a slightly rounded margin and as the development of the fish progresses this becomes more or less concave. In some species the caudal fin becomes round only after virtually all the adult characters are developed. Lebour (1919) has observed that the eyes which are situated on the sides of the head in the post-larval stage of gobiids, shift to the dorsal surface as the fish change their mode of life—the pelagic larvae descending to the bottom where the adult lives. An examination of the features of the larval development of the 'Chuno' shows that as in the European Transparent Goby, *Aphya pellucidus* (Lebour *op. cit.*), the development of this fish gets arrested at the post-larval stage. The body remains transparent throughout its life as in the post-larvae. The mouth which has become oblique in the post-larval stage remains so in the adult. The caudal fin does not get rounded in the adult and the eyes continue to remain on the sides. The fish is truly pelagic all through its life, and does not change to bottom living as is the case with most of the gobies.

BIONOMICS.

General.—*G. chuno* is an inhabitant of brackish water areas. It has been recorded from the estuary below Calcutta (Hamilton, 1822) and the Chilka Lake and the Salt Lakes of Calcutta (Hora, 1923). Koumans (1941) gives India, Singapore and Siam as the habitat of this species. Hora (1934) recorded the specific gravity of the water of its habitat in Chilka, and remarked that the salinity of the other pieces of water in which *Gobiopterus* lives is not known. Our observations are mainly based on collections made from the creeks of Baguranjalpai. The chlorinity of the water at the times of collection from June to December ranged from 0.06% to 0.97%, and the temperature varied from 80.6°F. to 89°F. The hydrogen ion concentration showed a range of 8.2 to 8.6. 'Chuno' has been collected by us from the enclosed mullet farms near Calcutta and the river Hooghly also; which shows that they thrive in standing as well as running waters. The fact that the young and adults were always collected in surface tow nets proves that they are truly pelagic in their habits. As already pointed out by Hora (*op. cit.*) the pelvic fins are united only half-way forming a funnel like tube which does not serve

as an adhesive organ, as is generally the case in other gobies. Our observations on live specimens in the laboratory confirm this.

Hora (1923) stated that he could not make out any definite striae in the central portion of the scales of 'chuno'. Though the sculptural details are not recognizable normally, when stained with alizarin the scales show clearly rows of circuli extending along the basal and lateral regions. Text-fig. 4 shows the scale of a mature specimen 24 mm. long. The nucleus is not visible, but 12 circuli which stop short of the apical margin can be seen. The scales do not show any sort of annuli formations. Colett (1878) and Lebour (1919) suggested that the European Transparent Goby, *Aphya*, dies after spawning and is probably an annual fish. Though further observations are necessary to say whether this is so in *G. chuno*, the absence of annuli formations on the scales and the fact that all the eggs in the ovary are of the same stage of maturity, seem to point to a similar condition.



TEXT-FIG. 4. The scale of a 24 mm. long specimen $\times 150$.

Food and Feeding.—Hora (1934) stated that the 'chuno' feeds on copepods and other planktonic crustacea. Analysis of the gut contents of 50 specimens ranging from 9 mm. to 24 mm. collected from Baguranjalpai, Hooghly and Ghutuari-Sharif showed that planktonic copepods formed the chief constituent of the diet. Occasionally nauplius larvae and in one specimen *Zoea Macrura*, were found. The gut contents of the young as well as the adult specimens were similar, indicating that no dietary change takes place during the growth of the fish. No noticeable local variations in the menu was observed. The stomachs of ripe females were invariably found to be empty, indicating cessation of feeding during breeding since the gonads occupy so much room that very little space is left for the alimentary canal to function. The upturned mouth, and the nature of the food taken, show that it is a surface feeder.

SUMMARY.

Gobiopterus chuno breeds during October to December in the Contai area. Generally there are 230–300 eggs in the ovary, and all of them are meant for a single spawning. Adult females can be distinguished from the males by the presence of stouter and more prominent genital papillae, and larger conical teeth on the jaws. The development of larvae from 1.7 mm. stage to the juvenile stage is described. It is inferred that the development of the fish is arrested at

the post-larval stage. The fish remains pelagic all through its life. Though the scales do not show any annuli formations striae can be made out in scales stained in alizarin. From the analysis of the gut contents, it is inferred that (1) it feeds at the surface on zooplankton, (2) the food of young as well as adults is the same, and (3) there are no appreciable local variations in the menu.

ACKNOWLEDGMENTS.

We are indebted to Dr. S. L. Hora and Dr. T. J. Job, for their help and encouragement. It is a pleasure to record here the help that we have received from Mr. S. Jones during the work. One of us (T. V. R. Pillay) is grateful to the National Institute of Sciences of India for the award of a Research Fellowship which gave him the opportunity to undertake this study.

REFERENCES.

- Colett, R. (1878). On *Latrunculus* and *Crystallogobius*, two remarkable forms of Gobioid Fishes. *Proc. Zool. Soc. London*, pp. 318-339.
- Hamilton, B. (1822). An account of the Fishes found in the River Ganges and its Branches. Edinburgh, p. 53.
- Hildebrand, S. F. and Cable, L. E. (1938). Further notes on the Development and Life History of Some Teleosts at Beaufort, N.C. *Bull. U.S. Bur. Fish.*, **24**, pp. 505-642.
- Hora, S. L. (1923). Fauna of the Chilka Lake Fish, Pt. IV. *Mem. Ind. Mus.*, **5**, pp. 712-769.
- (1934). The Systematic Position of Hamilton's Species of Gobioid Fishes from the Ganges. *Rec. Ind. Mus.*, **36**, pp. 383-490.
- Koumans, F. P. (1941). Gobioid Fishes of India. *Mem. Ind. Mus.*, **13**, pp. 205-329.
- Lebour, M. V. (1919). The young of Gobiidae from the Neighbourhood of Plymouth. *Journ. Mar. Biol. Asso. United Kingdom*, **12** (N.S.), pp. 48-80.

FACTORY EFFLUENTS FROM THE METTUR CHEMICAL AND INDUSTRIAL CORPORATION LTD., METTUR DAM, MADRAS, AND THEIR POLLUTIONAL EFFECTS ON THE FISHERIES OF THE RIVER CAUVERY.*

By S. V. GANAPATI and K. H. ALIKUNHI (Freshwater Biological Research Station, Government Fisheries, Madras.)

(With Eight Tables and one Map.)

(Communicated by Dr. S. L. Hora, F.N.I.)

(Received after revision November 19, 1949; read August 5, 1949.)

CONTENTS.

	<i>Page</i>
Introduction	189
Mettur Chemical and Industrial Corporation, Ltd., Mettur Dam	190
Effect of the factory effluents on the water and fish in pools formed in the Ellis Surplus	
Course during different seasons of the year	191
Attempts at disposal of wastes	195
Discussion of Results and Recommendations	197
Acknowledgements	198
References	198
Appendices	199

INTRODUCTION.

With the increased industrialization of the country, the part that chemical works and other similar industrial concerns play in the reduction of food supplies from fisheries, is becoming more and more pronounced. The toxic effluents from the different industries like chemical works, paper mills, artificial silk factories, sewage works, beet sugar factories, food canning factories, etc., which are generally discharged into the national waterways, are polluting vast stretches of natural waters rendering them uninhabitable for fish life. With the realization of the dangers of this pollution and the consequent destruction of tons of edible food fish, it has become a necessity to devise ways and means for the safe disposal of these industrial wastes. In India, while the problem is still not very acute, the few contributions already existing on the subject (Hora, 1942; Hora and Nair, 1944; Malden, 1943 among others) and the country's comprehensive industrial programmes are sufficient warnings for having careful vigilance on the nature and extent of pollution of the major rivers which besides affording very lucrative fisheries, sustain the almost entire tank fisheries in India by supplying fish seed.

The Godavari, the Kistna, the Thungabhadra and the Cauvery are the major rivers of Madras; and of these, the Cauvery alone fetches over two-thirds the total revenue from inland fisheries in the province. In the present communication an

* Published with the kind permission of the Director of Fisheries, Madras.

instance of pollution of the river Cauvery and the consequent large-scale mortality of food fishes, particularly in a conserved area, is discussed at length.

The factory effluents from the Mettur Chemical and Industrial Corporation, Mettur Dam, are polluting the river Cauvery at Mettur and cause large-scale mortality of fish. It is evident that if this practice is allowed to continue unchecked, the fisheries of one of the major rivers of the province will be seriously jeopardized sooner or later. Remedial measures have therefore to be promptly taken up in the interests of preservation of valuable food and game fish. The efficient and economical method of disposal of the factory effluents, depending upon their nature and local conditions is thus an urgent necessity. A detailed investigation of this biochemical problem was therefore carried out for three years (1945 to '48), and the results obtained, with certain recommendations for the future, are presented in the succeeding pages.

METTUR CHEMICAL AND INDUSTRIAL CORPORATION, LTD., METTUR DAM.

(a) *Location*: (Fig. 1. Map).

The factory is located very close to the Mettur reservoir at a fairly high level at the foot of a hillock which has a natural slope towards the Ellis surplus course. The area surrounding the factory is of a rocky nature. The nearest place where the factory effluents can be discharged is the reservoir, but the effluents will have to be pumped. The Ellis surplus course is also closely situated and because of the natural slope towards it the wastes can be easily discharged into it by gravitational flow. The rocky nature of the surrounding land precludes the possibility of disposal of the effluents on land.

(b) *The Factory Effluents*:

Quantity.—A fair idea of the quality and quantity of the pollutional wastes could be formed from the following list of the important products manufactured by the concern:

Caustic soda, bleaching powder, vanaspati, refined oil and bleach liquor.

It is obvious that waste products from sections producing caustic soda, bleaching powder and bleach liquor are likely to render the greatest harm to fish and other animal life. The approximate total quantity of the wastes emanating from the chemical works is estimated on an average at 10,000 gallons of liquid per day; but a much higher quantity, as many as 23,000 gallons per day, of the wastes will be produced when the plants are working at maximum capacity.

Quality.—Samples of the effluents have been examined and the results of a typical analysis are given in Table I. The carbonates and chlorides of calcium and sodium are found to be the dominant salts in the effluents. The large amounts of caustic alkalis and the excess of suspended matter are, no doubt, deleterious to fish life.

Weekly analyses of the factory effluents were carried out for over a year (April, 1946 to June, 1947) for studying the variations in the most important harmful substances such as hydroxide, carbonates, free chlorine and combined chlorine; and the range of variations and the monthly averages of these are furnished in Table II. The hydroxide content varies from 1.36 to 75.3 parts; carbonates (expressed as CO_3) from 0.8 to 27.53 parts; free chlorine from nil to 19.6 parts and total chloride chlorine from 31.5 to 424.8 parts per 100,000.

Welles (1915) found that fishes do not thrive in highly alkaline waters, but become sluggish and inactive. 'Salts present in excess or without the proper antagonistic salts or ions, and salts not commonly present in quantity in freshwater are toxic to freshwater animals' (Ward and Whipple, 1918). Carbonates are not

essential to the life of fishes and when present alone, are rapidly fatal because of their alkalinity. It is also known that the presence of an excess of calcium causes the tail fins of certain species of fish to degenerate and also tend to lower the metabolic activity of organisms.

EFFECT OF THE FACTORY EFFLUENTS ON THE WATER AND FISH IN POOLS FORMED IN THE ELLIS SURPLUS COURSE DURING DIFFERENT SEASONS OF THE YEAR.

Figure 1 illustrates clearly the location of the Stanley reservoir, the Mettur dam, the course of the Cauvery in the area, the Ellis surplus channel and the series of rock pools formed therein, in relation to the Chemical factory discharging effluents. The surplus course runs almost parallel to the river course, amidst large rocks and joins the main river at Kollanayagampatty, about three miles below the dam. The entire surplus course, from the point of view of pollution, may roughly be divided into two sections; the first, from the Ellis bridge down to Mattathuparai, and consisting of five almost continuous pools, and the second, from Mattathuparai (indicated by the line XY in Fig. 1) to the confluence with the main river and consisting of another set of six pools. Pools 2 to 5 of the first section which are smaller and are located at a comparatively higher level are interconnected and are directly polluted by the factory effluents. The first pool is situated slightly above the point of discharge of the effluents and is therefore not ordinarily contaminated. The pools in the second section are bigger and deeper and are at a lower level than the first set of pools. These pools are not directly contaminated by the effluents.

The factory effluents from the Mettur Chemicals flow by gravity through a meandering channel (Fig. 1) in the rocky ground for about a furlong and are discharged into the nearest pool in the surplus course. As the toxic effluents accumulate they flow into the neighbouring pools and pollute them. Pools 2 to 5 are most affected and during the non-surplussing months the water in these pools turns whitish with the accumulation of the effluents and is absolutely unsuitable for fish life.

With the construction of the Mettur dam across the river Cauvery the natural highway for the fishes from the lower reaches to the upper is cut; the flow of water through the high and low level supply channels and the power house turbines being of tremendous velocity the fishes are seldom found to negotiate these successfully and migrate to the reservoir. However, when the level of water in the reservoir reaches 100 feet the Ellis surplus begins to function, when the fishes are able to freely migrate upstream and thus overcome the barrier of the dam. The economically important carps and catfishes of the Cauvery breed during the rainy months, June to August and October to December. Depending upon the annual rainfall in the catchment area of the reservoir and the source of the river, the period of surplussing of the Ellis channel varies, and the migration of fishes for breeding purposes directly depends on the period during which the surplus channel functions. The following table gives the period during which the surplus functioned for the years 1945 to 1948:

Year.	Dates on which surplussing	
	commenced.	stopped.
1945	.. 1-1-1945	20-1-1945
1946	.. 8-8-1946	31-12-1946
1947	.. 1-1-1947	13-2-1947
1947	.. 1-6-1947	20-6-1947
1947	.. 27-8-1947	26-11-1947
1948	.. 26-7-1948	7-11-1948

Since during their upstream migrations thousands of fish (the major carps *Calla calla*, *Cirrhina cirrhosa*, *Labeo kontius*, *L. fimbriatus*, *L. calbasu*, *Labeo* sp., *Barbus dubius*, *B. carnaticus*, *B. hexagonolepis*, etc. and the catfishes *Mystus senegalensis*, *M. aor*, *Wallagonia attu*, *Pangasius pangasius*, *Silonia silonia*, etc.) congregate in the supply channels and the Ellis surplus course, a three miles stretch of the river, from the Mettur dam downwards has been declared a conserved area. The necessity for ensuring free movement of fish through the Ellis surplus course is thus obvious and any pollution of the waters in this only natural highway for the migration of brood fish is to be considered most seriously.

In the present instance, while the steady, year-round discharge of the effluents into the river system may have a cumulative effect on the waters, their pollutional effects are felt only during the summer months when the surplus channel does not function. The conditions of existence in the rock pools in the surplus course were studied both during the 'non-surplussing' as well as the 'surplussing' periods and the effects of the factory wastes on the fishes observed. The physico-chemical conditions of the wastes during the different seasons are furnished in Table III.

The effluents as they flow from the effluent pit in the factory to the surplus channel, undergo certain changes. The suspended solids largely settle down at the bottom of the drain and by the time they reach the surplus course, generally appear as a more or less clear fluid. When water overflows in the surplus channel, the effluents get readily diluted and except in the immediate vicinity of the point of discharge, the characteristic whitish discolourization of water is not seen. Chemical analysis of water samples also show that only the first pool is appreciably affected during this period (Table III, A). The very low chloride contents in samples from the first three pools clearly indicate the enormous dilution of the pollutants. The fishes are apparently not affected then by the pollutional discharges, and shoals of them could be seen migrating upstream. Several specimens of *Barbus carnaticus*, *B. filamentosus* and *Xenentodon cancila* were found in the immediate vicinity of the point of discharge of the effluents; and no dead fish were observed during this period.

With the fall in level of water in the reservoir, the flow in the surplus course also decreases. The conditions of existence in the surplus pools were studied during the last stage of overflow from the reservoir, for 6 days, from 18th to 23rd November, 1947 (III-A). The surplus course ceased to function on 26-11-1947. On 18th November, the level of water in the reservoir was 106.95 feet and 23,143 cusecs of water were overflowing. By 23rd November the level had come down to 100.35 feet, when only 17,437 cusecs of water were overflowing. The above flow was quite sufficient to dilute the toxic effluents and render them harmless for fish life. The biological conditions were more or less similar to the former period of full overflow and shoals of fish were moving upstream (Table IV-A). The first pool which received direct discharge of the effluents, was, however, avoided by fishes. The high alkalinity of water in this pool is to be attributed as the reason for this behaviour of fish.

With further fall in the reservoir level and the cessation of overflow through the Ellis surplus, the deep rock pools become isolated, and the thousands of carps and catfishes that were struggling to negotiate the torrential flow, get trapped in them. The neighbouring pools are connected together only by a meandering flow through narrow streamlets. With the steady accumulation of the toxic effluents, the hydrological conditions in the pools soon become absolutely unsuitable for fish life and large-scale mortality of the trapped fish takes place generally within a week or ten days after the surplus has stopped functioning (Tables III-B and IV-B). Even though this has become more or less a regular annual feature, no effective rescue operations like collecting the fish and releasing them into the reservoir, etc., are feasible since the rock pools are very deep, with steep sides and accessible only with difficulty. Thus the number of fish destroyed is very large and the

significance of this is increased severalfold when it is remembered that the fish trapped are mainly carp breeders and fingerlings. With the continued accumulation of the effluents the entire fish population in the first four pools is destroyed (*vide* Table IV-C and D).

A critical examination of the data furnished in Table III will show that the presence of toxic substances like free chlorine and hydroxide is mainly responsible for the mortality of fishes. When there is overflow through the surplus course free chlorine and hydroxide are absent in pools 2 to 5, but soon after flow of water stopped in the surplus channel, these toxic substances began to increase in all the pools and reached lethal proportions in a week's time. It is also seen that even with continued stagnation, lethal amounts of the toxic substances are present only up to the fifth pool and not beyond. However, during advanced periods of stagnation, the toxic substances undergo certain fluctuations probably due to the process of mixing, sunning and sedimentation and occasionally the free chlorine and hydroxide contents are diluted. A thick whitish slimy deposit of lime covering almost the entire bottom surface of the pools is characteristic during these periods of stagnation.

A general picture of the biological conditions of the polluted pools is obtainable from Table IV. As already stated, during the period of overflow, due to the excessive dilution of the effluents the fishes are not adversely affected. The rocky beds of the pools are almost bare without supporting any considerable algal growth, probably because of the torrential flow of water. Plankton is also very poor under the lotic conditions. With the fall in level of water, when lentic conditions prevail in the pools, algal growth is appreciable, but the first two pools are so surcharged with the toxic effluents that they do not support any plankton growth. Detailed observations (*vide* Table V) made on 26-6-1947, six days after the overflow through the surplus had stopped, show that fish life was absent in the first three pools, while in the 4th and 5th pools some fish were still present. Water in the latter pools was greenish in colour, mainly due to thick growth of *Oscillatoria*. Insect life was not very plentiful, though specimens of *Nepa* (with a white encrustation on the body) were seen swimming even in the first pool which received direct discharge of the effluents. Chironomid larvae were common in the marginal slimy encrustations. An uncontaminated pool (marked 'A' in Fig. 1 and item 8, Table V) above the point of discharge of the effluents, contained abundant fish life (*Cirrhina cirrhosa*, *C. reba*, *Labeo kontius*, *L. fimbriatus* and *Barbus carnaticus* were the dominant species) and no mortality had taken place in this pool. With continued stagnation and accumulation of effluents the conditions of existence in the first set of pools become more and more rigorous. Special observations made on 21st and 26th February, 1948 (*vide* Tables VI and VII) about three months after the surplus flow of water had stopped, indicate that while fish are still absent in pools 1 to 4, a large number of them were found in the fifth pool. Water in pools 3 to 5 was bluish-green or green in colour and a thick growth of *Oscillatoria* was characteristic. Dark, floating masses of this alga were numerous in pools 3 and 4. Several frogs could also be seen but no fish could either be seen or netted. In the shallower portions of the three pools (3 to 5) thousands of aquatic oligochaetes (Tubificids) could be seen and these rendered the bottom appear reddish in places. Their chloride contents are also considerably higher. Dissolved oxygen in the water (sample taken at noon on a bright sunny day) varied from 'nil' in pool 3 to 1.9 c.c. per litre in pool 5 (Table VII). The very low oxygen content and the abundance of worms at the bottom indicate excessive organic decomposition. Phytoplankton was not very rich and was represented in fifth pool by *Anabaena*, *Pediastrum* and *Pleurococcus* in the order of abundance. Zooplankton was fairly rich, consisting mainly of copepods (*Cyclops*) and rotifers (*Polyarthra*). *Barbus carnaticus* was the dominant species of fish while few specimens of *Labeo kontius* were also present. Ripe males, 8" to 9" in length, were common in the former species, while all the Labeos were of the fingerling stage.

The biological conditions of the pools (Nos. 6 and 8 in Table VII) in the second section of the surplus course, adjoining the fifth pool of the first section, offer interesting contrast. No mortality of fish had taken place in these pools and shoals of large fish, *Cirrhina cirrhosa*, *Labeo kontius*, *B. carnaticus*, *Labeo calbasu*, *L. fimbriatus*, *Labeo* sp., smaller barbels like *B. filamentosus* and fingerlings of *L. kontius*, *Labeo* sp., *B. carnaticus* and *C. reba* in hundreds could be seen in the surface waters, while the frequent scattering of these shoals by the violent movements of some larger fish clearly indicated the presence of predators like *Wallagonia attu*, *Myxus seenghala* and *Silonia silondia*. As is clear from Table VIII the harmful effects of the pollutants are not felt in these pools and even in advanced periods of stagnation (20th March, 1948, i.e. about 4 months after the overflow had stopped) free chlorine and hydroxide are generally absent. Their chloride contents are also comparatively lower. An abundance of plankton (zoo-plankton dominating) in spite of the presence of a rich fish crop, and the moderately high pH and dissolved oxygen values indicate the greater organic production in these pools as compared to the polluted ones.

Experimental Observations :—

The physiological responses of the fishes to varying concentrations of the factory effluents were studied under laboratory conditions and the results are tabulated below.

No.	Fish experimented.	Size in inches.	Proportion of effluent to Corporation water.	pH.	Parts per 100,000.		Fate of fish.
					Free Cl ₂ .	Chloride.	
A. Control							
1.	<i>Catla catla</i> .. <i>Etroplus suratensis</i> <i>Rasbora daniconius</i>	4.0 3.0-4 2.0	Corporation water only.	7.2	nil	10.4	All alive till end of experiment.
2.	Do. ..	do.	Factory effluent alone	>9.6	0.8	460.0	Instantaneous death.
B. Dilutions							
3.	<i>Catla catla</i> .. <i>Etroplus suratensis</i> <i>Rasbora daniconius</i>	do.	1 : 1	>9.6	0.6	235.2	All died in 5 minutes.
4.	Do. ..	do.	1 : 10	9.2	0.4	51.27	Do.
5.	Do. ..	do.	1 : 50	9.0	Trace	19.20	All died in 20 minutes.
6.	Do. ..	do.	1 : 100	8.6	Do.	14.85	All died in 6 hours.
7.	Do. ..	do.	1 : 1000	8.0	nil	10.84	All alive after 8 hours.

It is evident from the above that the three species of fish representing the major carps (*Catla catla*), the semi-exotic perch (*Etroplus suratensis*) and the carp minnow (*Rasbora daniconius*) were able to survive for over 8 hours in dilutions of about 1 : 1000, while in 1 : 100 dilution all of them succumbed within 6 hours. It is likely that the death of fish was due to the presence of free chlorine in the diluted samples.

A second series of experiments, using the top minnow *Gambusia affinis*, was therefore carried out to find out the lethal dose of free chlorine. Using bleaching powder containing 30.5% of available chlorine, chlorine-water was prepared such that 0.164 ml. of the solution was equivalent to 1.0 p.p.m. of chlorine. Seven beakers, each containing 500 ml. of pond water were arranged and three fish, 1.5" to 2.0" in length, were introduced in each. Varying volumes of chlorine water, as detailed hereunder, were added to the beakers of which one was kept as control. The following results were observed:—

No.	Chlorine-water added.	Duration.	Fate of fish.
1.	93.75 p.p.m.	3 minutes.	All died.
2.	62.50 "	5 "	1 died.
		15 "	2 died.
3.	18.80 "	15 "	1 "
		18 "	1 "
		20 "	1 "
4.	12.50 "	23 "	1 "
		30 "	1 "
		40 "	1 "
5.	6.25 "	90 "	3 "
6.	1.00 "	2 hours.	All alive.
7. Control.	Nil.	2 "	" "

It therefore appears that *G. affinis* is able to withstand 1 p.p.m. of chlorine in pond water. In the factory effluents free chlorine content has been found to vary from nil to 196 p.p.m., an amount that is more than double the dose that caused death of *Gambusia* in three minutes. The free chlorine content of the effluents is really high and is not ordinarily met with in any drinking water.

ATTEMPTS AT DISPOSAL OF WASTES.

With a view to find out effective remedial measures to check this annual heavy toll on the Cauvery fisheries attempts were made to neutralize the toxic effluents and dispose of them in such a manner as to be innocuous to fish life. Three methods were tried as follows:

(a) Neutralization with Hydrochloric Acid :

This method was tried by the factory authorities on their own initiative, since the required acid was being manufactured in the factory itself. They aimed at producing a neutral effluent with no trace of free chlorine, by installing an acid vessel from which pre-determined quantities of acid were allowed to mix continuously with the effluents as they were pumped out from the settling tank. However, the results of examination of the wastes before and after one such acid treatment showed that in more than 50% of the samples handled the hydroxyl (OH) alkalinity was still present as also traces of free chlorine, and the pH of the samples was as low as 5.7. From the economic aspect the cost of treating 1,000 gallons of the effluents in the above manner amounted to Rs.3.

A sample of the effluents, treated as above, was used to find out whether fish could thrive in it for any length of time. Using the reservoir water as control, it was found that fingerlings of *C. cirrhosa* and *C. reba*, 4 inches in length, died within 15 minutes when placed in a sample of the treated effluents. The low pH and the presence of caustic alkali and appreciable quantities of free chlorine (Trace to 0.2 parts per 100,000) were probably responsible for the death of fish.

(b) Recovery of the Effluents by utilization for water purification purposes.

The effluents contain appreciable quantities of caustic lime, free chlorine, chloride chlorine, fat, etc. Lime and free chlorine are two important substances

generally used in water purification. The former is ordinarily used for increasing the alkalinity of presedimentation waters before coagulation with alum as is now being done at Trivandrum, Bangalore and Mettur water-works. Houston's 'Excess lime' method of purification of river waters is also based on the same method. Chlorine is used in all water-works for the final disinfection of purified waters before distribution to a town's water supply.

In the present instance the excessive chloride chlorine and fat contents of the effluents might be objectionable for their use in water purification. The waste oils and fats mixed in the effluents could, however, be prevented from mixing with those from the alkali and other sections by suitable device. Laboratory experiments were therefore carried out with the effluents to ascertain the minimum amount of the wastes required for purifying raw river water from the Cauvery. Samples of river water were treated with the effluents at the rate of 0.5, 1.0, 1.5, 2.0 and 2.5 grains of calcium oxide (CaO) per gallon of water, and then with one grain of alum. A sample treated at the rate of 0.5 grains of CaO per gallon was analysed at the King Institute, Guindy, Madras, and was reported: 'Colourless and clear and appeared to be of very good quality from the chemical point of view.'

Finding that the effluents could thus be utilized for water purification purposes, it was necessary to ascertain whether all the effluents could be used locally. The 'Mettur Chemicals' are using about 0.17 million gallons of water daily for industrial and domestic purposes. If this water is to be treated with the effluents at the rate of 0.5 grains of CaO per gallon, the quantity required will be only 11% of the total effluents produced, the bulk of which will therefore remain undisposed.

The suspended solids in the effluents are now being trapped in large settling tanks inside the factory and occasionally discharged outside. The solids contain 60 to 70% of calcium oxide, but is relatively valueless as lime, owing to the presence of other constituents like basic salts of calcium chloride, etc.

(c) *Dilution.*

The possibility of effective dilution of the effluents before discharging into the reservoir, so as to bring down the caustic alkalinity within harmless limits to fish life, was considered, since plenty of water is always available (drought years excepted) in the nearby reservoir and since electrical energy at cheap rates is also available for pumping sufficient water to dilute the wastes. The effluents were diluted in the ratio of 1 : 9, 1 : 99, 1 : 999 and 1 : 9999, under laboratory conditions and the diluted samples were examined for their alkalinity, chloride chlorine and pH. It was found that 1 : 99 dilution of the wastes was most economical and safe from the point of view of alkalinity, chloride and pH, but the dilution experiments with Corporation tap water have already shown that even in 1 : 100 dilutions fishes could not survive for more than six hours. The cost of pumping 1,000 gallons of the effluents, together with water from the reservoir for the different rates of dilution was ascertained as follows:—

<i>Dilution.</i>		<i>Cost in Rupees.</i>	
1 : 9	0.38
1 : 99	3.80
1 : 999	38.00
1 : 9999	380.00

The maximum daily discharge of 25,000 gallons of the effluents, if to be diluted in the ratio of 1 : 99, would thus cost about Rs.95 per day (approximately Rs.30,000 per annum). An attempt was therefore made to dilute the effluents in the ratio of 1 : 10 on a large scale in the process rooms by pumping raw water from the reservoir. The hydroxide alkalinity of the diluted samples was, however, found to

be harmful to fish life and was therefore considered unfit for discharge into the Ellis surplus course.

DISCUSSION OF RESULTS AND RECOMMENDATIONS.

The effluents from the Mettur Chemical and Industrial Corporation, Ltd., Mettur Dam, Madras, are essentially liquids containing a high percentage of suspended solids due to calcium carbonate and fatty substances. They are also noxious due to the presence of free and caustic lime and free chlorine, but are potentially valuable on account of the presence of about 70% of lime (CaO). However, no recovery and treatment plants for CaO have so far been set up by the factory authorities, either because they tend to be costly or because pure calcite (96.0 to 98.0% CaO) is easily available in enormous quantities and at cheap rates from a neighbouring locality called Sankaridrug. The effluents were therefore being merely discharged into the nearby Ellis surplus course which serves as the overflow channel for the Stanley reservoir when its water level rises above 100 feet. But, as already detailed, the Ellis surplus course is a conserved area for the fisheries of the Cauvery and is the only natural highway for the spawning migrations of the economically important major carps of the river. It is also seen that so long as there is regular and continuous flow of water through the Ellis regulator, the fishes are unaffected by the effluents discharged into the channel; that when once the overflow is stopped, eleven pools of different sizes are formed in the bed of the channel; that the first five pools, extending from the Ellis bridge to Mattathuparai receive direct discharge of the effluents, resulting in total mortality of all fish life in at least the first four pools, and constitute the zone of pollution; and that the second set of six pools extending from Mattathuparai to the confluence of the channel with the main river, forms the zone of recovery. The accumulation of caustic alkalis and free chlorine in the water has been found to be the cause of mortality of fish trapped in the pools. The series of laboratory experiments carried out showed that even if the effluents are diluted with 100 times water, traces of hydroxide and free chlorine were still present and proved lethal to fish within six hours. Attempts were therefore made to find out some satisfactory method of disposal of these toxic effluents. The presence of considerable quantities of lime and free chlorine in the effluents made the same potentially valuable; and laboratory experiments showed that these wastes could be used for water purification purposes. It is therefore worth while to ascertain whether the raw water treated with the effluents would come within the standards of quality and purity generally set for a drinking water supply; and if so whether treatment and recovery plants for the effluents will be economically feasible. While it has been shown that the total daily requirements of water for industrial and domestic purposes of the 'Mettur Chemicals' will utilize only 11% of the effluents for purification purposes, the bulk of these industrial wastes could probably be disposed off if the Mettur and Salem town water supplies are also to be purified by using the same. If this is found a workable proposition, it will then be required to devise means to prevent the wastes from the alkali plants from mixing with those from the oil refining sections.

While recovery of the effluents for useful purposes, if feasible, is the best means of disposal, in the present instance the easy availability of pure calcite in sufficient quantities in the neighbourhood might render attempts at setting up recovery plants uneconomical from the company's point of view. Dilution of the wastes and thus rendering them innocuous to fish life would therefore seem to be the safest method now feasible and this can be effected by pumping the required quantity of raw water from the reservoir into the factory where the effluents are stored, and later diluting them in the ratio of 1 : 99 before discharging into the Ellis surplus channel. However, as already shown, this will involve some recurring expenditure and also will not ensure absolute immunity for the trapped fish since the diluted effluents

will be accumulating in the pools when the overflow stops in the surplus channel. Viewing the whole problem from the financial and practical aspects it is suggested that the effluents be taken by pipes to a place in the main river, below the in-take for the Mettur water works where the constant flow of water from the tail-race of the power house will ensure thorough mixing and dilution of the wastes. The lowest rate of flow from the tail-race is about 10,000 cusecs. Even at this rate of flow the maximum daily discharge of about 25,000 gallons of the effluents into the river will effectively be diluted over 5,000 times, so that no harm will be caused to the fishes in the area. The proposed site where the effluents may be discharged into the river is indicated in Figure 1. The effluents are to be taken by hume pipes from the factory, along the Ellis bridge and discharged into the main river. Since the level of the Ellis bridge is slightly higher than that of the effluent pit, it may be necessary to pump the effluents periodically.

ACKNOWLEDGMENTS.

Our sincere thanks are due to Mr. R. Natarajan, B.Sc., Secretary, Mettur Chemical and Industrial Corporation Ltd., Mettur Dam, for his invaluable help in affording us all facilities for carrying out this investigation; to Mr. N. V. Choodamani, B.Sc. (Hons.), Assistant Director of Fisheries and to the Inspector of Fisheries, Mettur Dam, for their ungrudging help in making all local arrangements and field observations.

SUMMARY.

Since the construction of the Mettur dam it has become an annual feature that a series of connected rock pools are formed in the bed of the Ellis surplus course when the water ceases surplussing. Thousands of carps and catfish are then entrapped in these pools. The factory effluents from the Mettur Chemical and Industrial Corporation are at present discharged into these pools. These effluents consist of an excessive amount of dissolved and insoluble solids, chlorides and free chlorine, and are highly alkaline due to the caustic lime used in the manufacture of bleaching powder. Since the pools are stagnant, the addition of these toxic wastes pollutes the waters and invariably results in large-scale mortality of the trapped fish, during summer months. With the Ellis surplus functioning, the pools overflow and the pollutional wastes are considerably diluted and rendered harmless to fish life.

With a view to prevent this annual mortality and the consequent depletion of fish stock in the conserved area, the conditions of the pools were investigated at different seasons during the years 1945 to 1948. While biotal life was not altogether absent in the polluted pools even under extreme summer conditions, those receiving direct discharge of the wastes and the neighbouring ones, with their offensive odour of caustic lime and free chlorine, were totally unfit for fish life of any kind.

Chemical treatment of the effluents and dilution before letting into the pools proved ineffective and uneconomical. The potential value of the effluents for purposes of water purification has been shown by laboratory experiments, and their recovery for the said purpose may be worth while if the bulk of the effluents could be disposed off in that manner. Since excessive dilution appears to be the easiest method to render the effluents innocuous, diverting the same to the main river to a spot close to the tail-race of the Mettur Power House has been suggested.

REFERENCES.

- Hora, S. L. (1942). A short note on the pollution of streams in India and its likely effect on fisheries. Report, Fish Committee, Imp. Coun. Agri. Research, India.
Hora, S. L. and Nair, K. K. (1944). Pollution of streams and conservation of fisheries: Effluent of the Quinine factory at Mungpoo, District Darjeeling, Bengal. *Proc. Nat. Inst. Sci. India*, **10**, 147-166.
Malden, P. R. E. (1943). River pollution and fish mortality. *Journ. Bom. Nat. Hist. Soc.*, **43**(3), 534.
Ward, H. B., and G. C. Whipple (1918). *Freshwater Biology*. John Wiley & Sons, Inc., New York.
Welles, M. M. (1915). The reaction and resistance of fishes in their natural environment to acidity, alkalinity and neutrality. *Biol. Bull.*, **29**, 221-257.

APPENDIX I

TABLE I.

The Results of a complete analysis of a Sample of the Effluents.

Date of Collection, 26th March, 1948.

(Results expressed in parts per 100,000.)

A. *Physical* :—

1. Appearance	..	..	..	..	Turbid.
2. Colour ..	..	..	..	..	Nil.
3. Odour ..	..	..	..	..	Nil.
4. Turbidity	..	..	..	..	4.2.
5. Sediment..	..	..	..	..	0.82 (CaCO ₃).
6. Reaction	..	..	..	..	Alkaline (pH 10.20).

B. *Chemical* :—(After filtering the sample.)*Determinations made :*

1. Total solids (dried at 100°C.)	..	..	..	..	199.23
2. Alkalinity (as CaCO ₃)	..	..	..	..	29.00
3. Silica (as SiO ₂)	..	..	..	..	1.26
4. Oxide of Iron and Alumina	..	..	..	..	0.032
5. Iron (as Fe)	..	..	..	..	Nil.
6. Lime (as CaO)	..	..	..	..	38.30
7. Magnesia (as MgO)	..	..	..	..	Nil.
8. Manganese (as Mn)	..	..	..	..	Nil.
9. Free Lime	..	..	..	..	29.00
10. Free Soda	..	..	..	..	3.00
11. Sulphates (as SO ₃)	..	..	..	..	Traces.
12. Chlorides (as Cl ₂)	..	..	..	..	84.80
13. Nitrates (as KNO ₃)	..	..	..	..	Present.
14. Free CO ₂	..	..	..	..	Nil.
15. Free Cl ₂ ..	..	..	..	..	0.20
16. Total Hardness	..	..	..	..	40.18

Hypothetical Combinations :

1. Calcium carbonate	..	..	..	..	17.80
2. „ sulphate	..	..	..	..	Nil.
3. „ chloride	..	..	..	..	9.90
4. Magnesium carbonate	..	..	..	..	Nil.
5. „ sulphate	..	..	..	..	Nil.
6. „ chloride	..	..	..	..	Nil.
7. Sodium carbonate	..	..	..	..	12.00
8. „ sulphate	..	..	..	..	Traces.
9. „ chloride	..	..	..	..	136.77
10. Potassium nitrate	..	..	..	..	Traces.
11. Silica ..	..	..	..	..	1.26
12. Fe ₂ O ₃ and Al ₂ O ₃	..	..	..	..	0.082
13. Combined water	..	..	..	..	Nil.

TABLE II.

The monthly averages and range of variations of the alkali and chlorine contents of the untreated effluents from the Mettur Chemical and Industrial Corporation, Ltd., Mettur Dam.

(Period: April, 1946 to June, 1947.)

(Results expressed in parts per 100,000.)

Period. April '46-June '47.		Alkali.			Chlorine.	
		OH.	CO ₃ .	Total.	Free.	Chloride.
April, 1946	Average.	28.58	..	28.58	3.23	180.58
	Range.	8.6-75.3	..	8.6-75.3	Nil-4.9	122.5-246.0
May, 1946	Average.	11.86	..	11.86	0.48	210.7
	Range.	3.4-22.6	..	3.4-22.6	Nil-2.4	131.4-420.0
June, 1946	Average.	27.06	12.5	31.45	1.4	219.72
	Range.	2.2-47.6	12.0-13.0	15.2-47.7	Nil-5.6	71.0-424.8
July, 1946	Average.	15.08	7.73	22.81	0.71	263.3
	Range.	1.36-34.0	3.0-18.0	6.16-52.0	Nil-2.4	31.5-560.0
August, 1946	Average.	21.18	8.2	29.38	3.76	175.0
	Range.	1.7-51.2	3.0-24.0	4.7-75.2	Nil-8.4	84.0-490.0
September, 1946.	Average.	13.76	3.6	17.36	0.82	100.33
	Range.	7.8-22.6	1.2-6.0	9.0-28.6	Nil-2.1	35.0-161.0
Dec., 1946	Average.	11.0	2.0	13.0	2.45	135.13
	Range.	7.1-15.6	1.2-3.0	8.3-18.0	Traces-5.3	38.5-252.0
Jan., 1947	Average.	14.16	2.48	16.64	2.0	134.4
	Range.	8.4-25.6	1.2-6.2	10.0-31.8	Traces-5.2	86.0-256.0
Febr., 1947	Average.	15.75	10.21	25.96	6.92	86.1
	Range.	6.5-37.4	0.8-27.53	9.2-41.57	Traces-13.82	64.0-94.0
March, 1947	Average.	25.53	3.48	29.01	1.9	141.1
	Range.	12.4-30.4	0.8-5.5	13.2-34.0	Traces-7.6	48.4-296.0
April, 1947	Average.	16.18	2.76	18.94	4.92	153.8
	Range.	5.8-25.8	1.1-5.8	7.3-31.2	Nil-15.2	115.0-210.0
May, 1947	Average.	17.42	2.28	19.70	3.36	222.8
	Range.	12.4-20.8	0.8-5.4	13.2-26.2	Nil-13.0	162.0-258.0
June, 1947	Average.	15.7	3.33	19.03	5.75	177.5
	Range.	12.4-21.3	1.7-6.2	14.8-24.5	Nil-19.6	128.0-264.0

FIRST CHANDRA KALA HORA MEMORIAL LECTURE.

GROWTH OF THE FISHING INDUSTRY: SIDELIGHTS ON FIFTEEN YEARS' WORK.

By S. B. SETNA, M.Sc., Ph.D. (Cant.), F.N.I., Director of Fisheries, Bombay.

(The Lecture was delivered at the Annual General Meeting of the Institute, held at Poona, on Monday, the 2nd January, 1950.)

I think myself singularly honoured to be called upon to address this assembly. I realize that I have a formidable task before me and that I must be careful in speaking of fish for the subject is not only a fishy but a tricky one. I am reminded of the words of David Star Jordon, Chairman of the International Fisheries Commission, who once remarked that as sharks lie on the bottom of the sea and trout lie in the streams there can be no just complaint if men who fish for them also lie. I assure you that I shall be an exception, as I do not view with pleasure the prospects of being pulled up.

I confess that it is with much diffidence that I attempt to discharge the task entrusted to me today. The subject of my discourse is beset with numerous difficulties but these are resolved, to some extent, by the terms governing the award which the Council of the National Institute of Science has been pleased to bestow on me. I am expected to address you according to the terms of the award on the subject of my work. The theme is not novel, and having devoted more than half of my lifetime to the study of fishes, in one form or another, I think I may be able to present to you a picture, incomplete, I fear, of such results as I have been able to achieve.

The theme of my address is, to put it in a nutshell, the subject of my work, which, fortunately or unfortunately has so many ramifications and touches the life

of the fishermen and their industry at so many points
Theme of discourse. that I do not know what to say, leave alone where to begin.

I hope I shall not be considered to be lacking in modesty when I claim with all humility, that the Fisheries Department now under my charge is, to a large extent, a creature of my making. I played the rôle of a midwife at its birth. The infant of that day has grown to be a lusty child, having successfully overcome its teething troubles. It promises to become in the fulness of time a worthy giant in our country's life, provided that we show foresight in our approach to its various problems.

The year 1934, seems to me but yesterday, for I vividly recall at this moment the frail fishing craft (Plate IX, fig. 1), equipped with only a nine horse-power engine, which slipped down a suburban beach to inaugurate the

Start of New Era. start of a new chapter in the fishermen's life which till then had appeared changeless through the centuries. That event was symbolic in two senses. It marked not only the introduction of the use of power-propelled craft in the fishing industry in Bombay but also the beginning of the present Fisheries Department.

Till then, the means of transport of fish from our fishing fields to the city had been at what, for the lack of a more expressive term, might be called the bullock-cart stage. The bulk of our supplies of fish was derived from areas in the sea within easy reach of the city. Supplies from further afield were wheeled to the city by train and cart or brought by sailing craft. Fishermen were content to pursue their calling very much as their ancestors had done for countless centuries. The

performance of that small vessel which slipped down the suburban beach opened up a new vista to the fishermen in our province.

The sphere of operation of the vessel was expected to be 20 miles north and south of Bombay, but the vessel, frail as it was, made history. Risks were taken and the range of voyages has gradually widened. Every

Stimulus to progress. achievement, howsoever insignificant and paltry, was an incentive to further effort.

The launches, built for a specific range, have shown themselves to be possessed of the attributes of the seven-league boots. Their range of operations extends now from the Makran Coast, off Baluchistan, in the north, to Coondapur in Madras Province, in the south. The distance traversed on the round trip to Makran is about 1,400 miles, and that to the south 900 miles. Always, the impulse has been fresh fields and pastures new, with the prospects of larger harvests from untouched regions of our extensive coastline.

Not a year has elapsed since 1934 without newer, better and more powerful vessels being put into commission. Stimulus to progress has been provided by the existence of rich fishing fields which came to light when one or another of the launches chanced to visit them. The operation of the launches has conclusively established that there is no part of the coastline of this province, or even beyond, which cannot be made to serve our city's needs.

The success which attended the operation of the initial launch has kindled many enterprises, which have now become vital and indispensable features of the trade.

Villages awaken. The operation of the launches has brought unforeseen prosperity not only to diverse concerns but also, above all, to the sleeping fishing villages on the coast, which have been awakened from their centuries-old slumber and galvanized into activity befitting our modern age.

The number of vessels comprising the fishing fleet today is over 48, representing a total capital investment of about 40 lakhs of Rupees. The largest vessel in service tapes 112 feet from stem to stern, and is equipped with diesel engines developing 500 horse-power (Plato IX, fig. 2). A vivid idea of the vessels in service, their dimensions, their B.H.P. and their value may be formed from the statement pp. 218-19.

The successful transport of fish in these vessels has incidentally served as an eye-opener. It has indicated the great scope for their use as a means to develop the commerce and trade of the coastal regions. One respect in which these launches surpass regular coastal steamers in their easy manoeuvrability and the extraordinary facility with which they can worm their way into, and out of, narrow channels and creeks leading to inconspicuous ports which cater for the needs of their particular area. There is a vast and promising future for launches of the present description and it is no vain hope that in the years to come a good deal will be heard of the use of small power-propelled craft to minister to the requirements of growing industries all along India's coastline.

The figures below will enable you to form some idea of the expanding volume of fish brought by the launches to the city.

Year.	No. of launches.	Weight of fish. lb.
1933-34	.. 2	55,520
1934-35	.. 2	1,66,125
1935-36	.. 3	2,39,446
1936-37	.. 3	4,04,679
1937-38	.. 4	5,17,964
1938-39	.. 9	15,76,682
1939-40	.. 9	25,04,000

Year.	No. of launches.	Weight of fish. lb.
1940-41	.. 9	22,64,000
1941-42	.. 10	27,24,000
1942-43	.. 8	28,34,000
1943-44	.. 9	11,54,000
1944-45	.. 11	12,18,000
1945-46	.. 15	30,04,341
1946-47	.. 23	30,86,425
1947-48	.. 30	35,00,000
1948-49	.. 50	63,16,828

By far, the greatest boon accruing from the operation of the launches is the unparalleled activity their presence has led to in small fishing centres along the coast. Fishermen there now strive their utmost to make **Fishermen energized.** as large catches as possible. The launches bring, as it were, Bombay's rich market to their very door-step, where, without the trouble of coming the long distance to Bombay, they can dispose of their catch at prices far more remunerative than those which they obtained in their villages when there were no launches (Plate X, figs. 1 and 2). Figures will speak eloquently of what the launches have accomplished. Prior to their appearance along the coastal villages, mackerel used to be sold at about 12 annas to a rupee per thousand. Today the very fish fetch the fishermen anything between Rs.15 to Rs.60 per thousand, a price which represents a substantial improvement of their economic condition.

Moreover, in the old days, before the launches started plying fishermen either cured or converted into manure such fish as they could not sell to their neighbours. The launches have been a sort of master key which have unlocked to them wealth which was beyond their ken a few years ago. One estimate, by no means exaggerated, suggests that fishermen in the Ratnagiri and Kanara District alone derived last year Rupees four lakhs, compared with barely Rs.10,000 obtained by the very fishermen in 1935, when the launches first made their appearance there.

The significance of their increased earnings is plain. A great amount of new wealth has poured into areas, which were proverbially noted for their backwardness. The purchasing capacity of the fishermen there has greatly risen, as is reflected not only in their more prosperous condition but also in their improved mode of life. At the same time, there has been a mental awakening among fishermen, who show signs of eagerness to modernize the industry.

One noteworthy sign of this mental awakening is to be seen in the increasing tendency among fishermen to identify themselves more intimately with the trade than before. Statistics are not available but there is evidence that fishermen, instead of forsaking their craft for easy sources of revenue, are concentrating more enthusiastically on the development of their industry which they now realize is as profitable as any other line of business.

It had never been expected that a 14-foot vessel, equipped with a 9 horse-power engine, would germinate into a fishing fleet unrivalled in the country. We are a far way behind European, American and Japanese standards, but compared with 1933, Bombay today can boast of some progress.

Curiously enough, the launches have not led, as anticipated by their original opponents either to any diminution in the volume of fish which fed the fish curing

Fears falsified. yards or to a dearth of supplies in the coastal areas they served. On the other hand, the fish curing yards have registered a progressive increase in their sale of salt. Their turnover is much larger than at any time before the appearance of the launches. This will be evident from the figures on the next page.

Year.	Quantity of fish cured in maunds.
1925-26 to 1927-28	.. 5,43,835
1928-29 to 1930-31	.. 6,05,061
1931-32 to 1933-34	.. 5,15,320

Department established in 1933.

1934-35 to 1936-37	.. 5,62,480
1937-38 to 1939-40	.. 5,82,570
1940-41 to 1942-43	.. 7,32,453
1943-44 to 1945-46	.. 7,72,612
1946-47 to 1948-49	.. 7,71,929

The unremitting efforts fishermen make to augment their catch in order to meet the needs of launches have proved a blessing in disguise, for not only people along the coast but also in its hinterland get more fish than before. Availability of larger supplies in these areas does by no means signify that their demand has been met to the maximum. This is not so, for the areas are capable of absorbing much larger quantities than now find their way thither.

The universal complaint, today, whether in Bombay city or in the districts, is scantiness of supplies, despite the threefold increase in the quantity of fish

Tastes change. now brought to the city's markets. The quantity of fish landed in Bombay in 1934 was 10,000 tons, whereas today it totals 30,000 tons.

Such modernization as has now marked the industry would, five years ago, have encouraged the hope that supplies were at least on the way of balancing the demand. These expectations have, however, been nullified by the unparalleled influx of refugees, nearly 90 per cent of whom eat fish. Another totally unexpected addition to the ranks of fish eaters is the labour class. Fish was, not long ago, a monopoly of the wealthy and near-wealthy but this comestible is today in ever-increasing demand among those belonging to the humbler walks of life.

Many of our indigenous labourers were formerly vegetarians from necessity and not by choice. Times have, however, changed and not only our labourers but also their palates have changed. This change is due to the larger pay packets they now receive. Thus, the influx of refugees and the higher purchasing capacity of the toiling masses have completely offset what might have been the normal benefits of the increased quantities of fish landed in the city. The advantage of the increased catches of fish, which are almost treble those of pre-war years, is thus only illusory.

The problem now before us is extraction of more fish from the sea, and its effective solution will overcome the present perplexing issue of inequality of supplies

Mechanical methods. to demand. The problem of the use of power-propelled vessels and mechanically operated nets for the capture of fish is, however, not singular to our province, but confronts every province in India which has anything to do with fisheries. This remark will conjure up pictures of superships of the industry, such as trawlers and draggers, which bring to markets of western countries voluminous supplies of fish. The effectiveness of these vessels is unquestioned, as has been amply demonstrated by trawlers which have operated in our waters. Sizable hauls have been made by trawlers in Bombay, Bengal and Madras, but an unexplained fact is that these vessels have not been financially successful, as the cost of their upkeep, loss and damage to nets far exceeds the amounts derived from the sale of their catches. The economics of this type of vessels must be closely examined from every point of view, to ensure that they do not prove to be liabilities.

Experience underlies the advisability of caution in the introduction of such large vessels in our waters as the economy of our fishing industry is not yet fully prepared for startling innovations. Only thus will every step forward be not only consolidated but interlinked with what has previously been achieved. In the fishing industry, unlike most other commercial enterprises, humble beginnings are preferable, specially for people unacquainted with the achievements of modern science.

Even the United States, which is accustomed to technological development on a mammoth scale, prefers small boats for the industry, although its turnover amounts to millions of dollars. I observed during my short stay there, the useful and valuable rôle played, both on the Atlantic and Pacific coasts, by vessels built on small proportions, and equipped with engines of small B.H.P.

Mechanization cannot be attained over-night. Approach to it has to be cautious, due regard being paid to the age-old customs and prejudices of people still accustomed to a primitive economy and mode of life. No useful purpose will be served if the practices and technique of the fishing industry in the countries of the west are to be superimposed on our fishermen without measures being taken, simultaneously, to acquaint them with the rudiments of mechanization. The most prudent course, in the circumstances, would be to associate the fishermen, from the very outset, with every scheme designed for the improvement of their craft. This objective has been in the forefront of every programme to secure not only betterment of the fishermen and their economic condition but also improvement of the meagre supplies of fish available to the public.

Our fisheries are most productive shortly after the monsoon, fish being available at no great distance from the shore. The fish begins to disappear mysteriously towards the end of the year when the shoals become progressively thinner, compared with the densely packed shoals which early in the season approach the shores, resembling in volume and extent very much waves of troops converging or falling on a key target. Catches soon after the monsoon are plentiful, whether fishing operations are carried out by power-vessels or sailing craft. Extensive use of either of these types of small vessels will yield maximum results.

This view is borne out by the observations of Dr. J. O. F. Hardenberg who was head of the Laboratory for Investigations of the Sea at Batavia. He expressed the opinion that our country's fisheries were scattered over wide areas and that only the promotion of small enterprises would furnish an estimate of the total potentialities.

In the circumstances, the most effective methods for capture of fish would be, at least, in the early stages, use of small powered vessels in conjunction with the various types of drift nets and long lines, as these can be employed both in comparatively shallow and deep waters. The shallow waters are, according to our present knowledge, most productive, as is evident from the satisfactory catches made by fishermen even now by their primitive methods. Some of these are most ingenious, and every effort must be made to adapt them to the modern requirements of the industry.

A method of fishing which appears likely to yield fruitful results is the use of the purse-seine, which is extensively employed by American fishermen both on the Atlantic and Pacific coasts.

The purse-seine represents the acme of American fishing skill. Its British counterpart is the ring-net as used by Scottish fishermen at Whitby in Yorkshire. The basic principle of fishing is the same, *viz.*, to surround the fish and purse the mouth. There is, however, a variation in the technique which differs according to the type of fish to be bagged. The basic principle of the purse-seine has remained, fundamentally, unaltered throughout the years, changes having been made in the light of experience as well as experiments in the actual handling of the nets. This

has resulted in a saving of human effort, enabling the fishermen to make sets expeditiously.

The opportunities I have had to accompany, purse-seine and ring-net fishing vessels convince me that they are the most effective weapons for the capture of fish and their introduction in our waters to capture mackerel, in the first instance, would furnish the answer to most of our problems. The efficiency of the net is more than established by the fact that it is the basis of the flourishing canneries which exist in the U.S.A. and U.K. Canning of fish would not be the paying industry without copious and unfailing supplies of fish, which are made possible by the use of purse-seines.

Results achieved by the advanced fishing industry in other parts of the world conclusively show that the basic factor, on which improvement of the industry hinges is the increasing displacement of the present sailing boats by power boats. The example of Japan in this respect is a lesson we must not only read but re-read. Japan's leadership in fish production and exploration of new fishing grounds did not just happen. It was carefully planned. About the beginning of the century Japan's fisheries were conducted in primitive sailing craft. In 1941, the Japanese fisheries used 72,000 power vessels to make their catch.

I have all along felt that the fishermen have to be carried with us if experiments are not to end unsuccessfully. They have to be made to feel that they have a stake in the success of the experiments, for, without this conviction on their part, all official enterprise will be, at most, of academic interest.

My Department's next move is to show that just as power-craft have replaced sailing boats for the transport of fish, so also mechanized vessels can be used to

New types of boats. catch fish. With this end in view, power vessels corresponding, in essential features, with the present undecked sailing boats have been built (Plate X, fig. 5). Engines of suitable horse-power have been installed in these vessels, so that fishermen are able to venture a little further afield for the capture of fish than they have been traditionally accustomed to. In addition, fishermen are being encouraged to use their existing nets from powered vessels. One such vessel specially designed and built for the purpose is the 'Tapase' (Plate X, fig. 6). She is about 50 feet in length and is equipped with a 165 B.H.P. Grey Marine diesel engine. Encouraging results have attended initial efforts and the hope is justified that, in the fulness of time, the present unpowered craft will be replaced by boats operated mechanically.

The success which has attended such small attempts at mechanization has given a much needed jolt to our fishing villages and roused them into action. Fishermen from remote parts of the coast have been addressing the Fisheries Department in ever-growing numbers for the grant of financial assistance to enable them to go in for mass mechanization. Fishermen have become conscious of their importance in the daily scheme of life. They desire, while they serve the public, that the benefits of their trade should remain with them and are equally eager to concentrate as much of it as possible in their own hands.

Their youths show keenness to qualify as mechanics and navigators of power fishing vessels, so that they can operate their own vessels and conduct the industry on a self-contained basis. This tendency is all to the good, because, though the industry is being gradually mechanized, the elders in the trade feel that their hereditary occupation is not denied to their sons. Generous facilities have been provided to enable fisher-youths to acquire training to operate power vessels and so far 30 youths have been trained and awarded certificates from the Mercantile Marine Department. Stipends are provided to pay for the maintenance of youths during the period of apprenticeship.

The number of youths who can qualify is limited, however, for training facilities are not numerous. Thus, modernization of the conditions now obtaining in the

fishing industry is bound to take some time. Even the removal of the so-called primitive methods and the introduction of modern technique are no guarantee of provision of supplies in such a measure as to outstrip demand. Introduction of mechanized methods of fishing is only one, but not an overriding, aspect of the problem.

Augmented catches will be of no avail if vessels bringing them to port cannot enter harbour on account of inadequate docking and landing facilities. These difficulties are real, and the need for their removal has forcefully been brought home to me by my personal observations at various points along our coast. Efforts are being made to overcome these obstacles. Although my views apply mainly to Bombay, I think, nevertheless, some description of what is being done to promote expeditious entry of fishing vessels into the dock will be of general interest, as conditions in Bombay must be parallel elsewhere along the coast.

Obstacles to be cleared.

An example of the manner in which such obstacles are being successfully surmounted is provided by measures now in hand to make Sassoon Dock a fish landing site in Bombay, thoroughly accessible to the present fleet at all stages of the tide and in all conditions of the weather. The basin is being dredged, so that the greater depth of the water will enable launches to enter and leave it freely.

Provision is also being made for the vessels to fuel rapidly and take aboard supplies of ice. Three oil companies are putting up installations to enable fuel to be fed directly from storage tanks into vessels. The advantage of this facility is patent, as launches will no longer be needed to store their requirements in drums which cluttered up the bunder.

In tune with these facilities derricks are being installed for rapid unloading of catches brought by fishing craft. At the same time, cement concrete floors and sheds have been provided, so that fish landed is disposed of in a hygienic manner and in conditions affording protection from the effects of the sun's heat (Plate XII, fig. 1.).

Likewise, it is not generally realized that many fishing ports along the coast have to put up with insufferable handicaps arising from siltage, obstruction by rocks, decay of such makeshift piers as exist, existence of thick mangrove swamps, absence of navigation lights, and above all, lack of water both for drinking purposes and washing nets. The inevitable result of this chain of difficulties, existing not only in the Bombay province but also, perhaps, at every stretch of our extensive coast-line, is, unnecessarily to thwart the expeditious turn-round of our fishing boats. Removal of such difficulties is as urgent, if not more important than, as the adoption of measures to augment the quantity of our present catch.

These problems have not received the attention they deserve in our country and their neglect is bound to handicap whatever reforms may be contemplated for improvement of the industry. Recognizing the importance of easy passage to and from docks, my department has accorded major priority to these problems.

No less important than provision of suitable docking facilities are the twin problems of marketing and refrigeration. Efficiency of marketing is as vital as

Marketing of fish.

the capture of fish. Arrival of large catches is in vain if the fish does not reach the consuming public quickly enough. Conditions prevailing in almost every market in the country without exception are utterly unsatisfactory, as fish is not always made available to the public as quickly as is desirable nor sold under the most hygienic and sanitary conditions. I shall speak of the main market of Bombay, but I am sure that my observations hold good of fish markets in Calcutta and Madras.

Bombay's main market, which was constructed at a time when the city's population was 3,00,000 has now to cater for a little over 3 million people. It has, thus outlived its usefulness. The congestion in the market during the brisk hours of business in the morning is so great that the public does not have a reasonable

chance to see the fish displayed for sale. If conditions are such in the city's foremost market, they are even worse in the others, the total number of which is 27. There are, however, hopes of the various shortcomings now characterizing the city's main wholesale fish market being overcome at an early date, as measures have been initiated by the Municipality to enlarge the present floor space of the market from 7,000 cubic feet to 17,000 cubic feet. The old market has already been pulled down and a new two-storeyed structure is being reared on the site of the existing building, though the blue-print provides for the construction of three additional storeys.

If the future population of not only Bombay but other great and growing cities is to be served, it is necessary that we must plan today for the needs of tomorrow. Production of more fish and provision of landing and marketing would be fruitless, without at the same time, the adoption of adequate measures for its conservation.

Provision of ice factories.

With this end in view, the establishment of ice factories and cold storages have been generously encouraged. Accordingly, the production of ice has been substantially enlarged, so as to provide for all contingencies. The total production of ice today is over 700 tons compared with a daily output of 300 tons before the war. The present output does not, however, represent the maximum quantum which will be yet larger as soon as electrical energy is fully available.

Bombay is not, however, an isolated unit. It is vitally interlinked with the hinterland which serves it. The provision of modern amenities in Bombay without the availability at the same time, of like facilities along the coast would be in vain. The coastal regions cater for Bombay's needs to an extent not appreciated by the average man. Accordingly, facilities for the erection of plants in the coastal areas have been granted by the Government on a two-thirds loan and one-third subsidy basis. These facilities have been made available to only fishermen's co-operative societies. One such plant is being erected by the Government for the benefit of fishermen at a fishing centre near Bombay at a cost of Rs.1,40,000. The plant will be made over to fishermen, who will operate it. Rs.46,000 of this amount is a free grant by Government to the village.

Plans are also contemplated for the erection of two plants by Government for fishermen, one at Versova in the Bombay Suburban District, and another in the Kanara District. The Government's foremost consideration is that the fishermen must be made to realize that they have a stake in the maintenance and prosperity of the plants provided. The Government's attitude towards the fishermen is one of sympathy, but, at the same time, the Government is determined that fishermen must cultivate the habit of self-reliance.

Refrigeration and cold storage are, however, modern methods for the preservation of fish. There are other age-old processes which our fishermen have practised for countless generations in common with fishermen the world over. The commonest process is that of curing fish with salt.

Fish Curing Industry.

Bombay Province has 34 fish curing establishments along the coast, stretching from Boria, in Ratnagiri District, to Bhatkal, in the Kanara District. These establishments play a valuable rôle in the economy of fishing villages, for, apart from retaining in the fish trade a large number of fishermen who might, otherwise, have drifted to other pursuits, they serve to make available supplies of fish in the hinterland where no fresh fish is to be had. The value of the fish curing establishments is, thus, unquestioned, as they provide, in a large measure, food for the poor and help them to have a varied diet.

The yield of cured fish averages 3,90,000 maunds annually, requiring the use of 1,10,000 maunds of salt. The yards are an integral part of the fishing industry, and improvements (Plate XII, figs. 2 and 3 and Plate XI, fig. 1) have been planned to modernize them at an estimated cost of Rupees nine lakhs. The improved facilities comprise:

- (1) Construction of cement concrete platforms to replace mud floors;
- (2) Construction of permanent super-structures over the platforms to replace thatched sheds ;
- (3) Sinking of wells, and provision of pumps and storage tanks;
- (4) Enlargement of storage capacity of salt godowns.

The provision of these facilities has greatly benefited fish curers and the fish curing industry, as experience has shown that a reduction of 20 per cent can be effected in the quantity of salt consumed under the former insanitary methods. The benefits of these facilities have been reflected in an improvement, desirable from every point of view, of the cured produce.

The fishing industry in our country, more than any other branch of occupational endeavour, requires to be encouraged to cultivate the virtue of self-reliance, for, as conditions now stand, the majority of our fishermen are, generally, at the mercy of money-lenders. Accordingly, active steps have been, and are being, taken to encourage fishermen to form co-operative societies, so that they are able to conduct their trade on a self-sufficient basis. There are at present 48 societies in all. Not many months have elapsed since the establishment of a central organization of fishermen, the Bombay Provincial Fishermen's Co-operative Association. Its progress has been most encouraging. So successful has been the enterprise that middlemen have been completely eliminated from several villages. The fishermen do their own transporting and marketing, as this enterprise has yielded substantial profits (Plate XI, fig. 2). The fundamental objective of the Association is to undertake the marketing of fish caught by its members, so that the profits realized are distributed among fishermen and are not diverted into the pockets of middlemen. The turnover of the society, it is expected, will reach about Rs.12,00,000 during current year. The Association has arranged for the transport of fish caught by members of co-operative societies in villages along the coast, which are affiliated to it. This arrangement is gradually being extended to villages both north and south of Bombay.

The Bombay Provincial and other co-operative societies have been put into touch with manufacturers of twine in Hungary and Italy and manufacturers of hooks in Norway so that members of their societies can obtain twine and hooks at reasonable rates. Depots are now being established by these societies at main fishing centres for the sale of fishermen's accessories.

It will thus be seen from what I have said that we have been striving throughout to introduce changes gradually, so that the fishermen are convinced of their advantages, readily adopt them and do not feel a wrench when they forsake their age-old methods. Such reforms as have been introduced in the fishing industry have been rendered possible by the financial assistance afforded by the Government. Loans to the extent of Rupees nine lakhs have been advanced to the industry on generous terms during the past five years. Nearly 60 per cent of the advances have been repaid. The proportion of recovery is, indeed, creditable in view of the chronic indebtedness and poverty of fishermen in our country as a whole.

No survey of the fishing industry in the Bombay Province will be complete without a passing reference to its ancillary activities. Progress achieved in this

Shark Liver Oil Industry.

direction is not spectacular but it is encouraging. Such progress as has attended various enterprises undertaken on a small scale show that they are capable of germination into thriving industries, which are bound to exert a noticeable influence on the development of the country's economy. Proof of this is afforded by the increasing popularity which has attended the manufacture of shark liver oil. The stimulus for this maiden enterprise was provided by the war when supplies of cod liver oil were interrupted on account of the German occupation of Norway. Bombay quickly seized the opportunity presented to put on the market a product which

would not merely be a substitute for cod liver oil but would effectively displace it. In 1939 the output of neat shark liver oil was but 400 gallons. Today it is about 5,000 gallons, which is not only sufficient for our needs but also provides a substantial exporting surplus. During the past year the department exported 3,500 gallons of oil worth Rs.86,000 to the U.K., U.S.A. and Australia.

Shark liver oil is, however, not everybody's meat, for its characteristic effluvia, in common with that of most fish liver oils, tends to nauseate people. Accordingly, the next venture was to concentrate on its sale in a manner which would appeal to the palate of consumers. We have succeeded in putting on the market shark liver oil in capsules, so that it can be taken by even the most fastidious and delicate palates. Encapsulation of shark liver oil is a pioneer enterprise in the country. There is little doubt that with the changed tastes of our people and with the growing recognition of the important part played by tonics in the national health the popularity of the shark liver capsules will grow.

Finally, I come to scientific research which, in the ultimate analysis, is the basis of progress in any endeavour nowadays. It has not been neglected while

Scientific Research.

commercial expansion of the industry has been pursued. The department will soon have an up-to-date aquarium in Bombay, where not only fishes will be exhibited but Marine Biological Research carried out. Schemes are also afoot for the establishment of a Marine Biological Station at Ratnagiri. In addition, the scope of the work at the Technological Laboratory attached to this department is to be enlarged. The total cost of the station in Bombay alone will be about Rs.10,00,000.

I have come now very nearly to the end of my talk. I have touched, I feel, on almost every facet of what has been accomplished in the field of fisheries. One fact,

Duplication of efforts.

and it is an unattractive feature which has somehow or the other impressed itself on my mind, is the apparent lack of co-ordination of effort in this country. I do not seek to be critical, as I am painfully aware of my own limitations. Yet, I feel that I should be lacking in candour if I failed to give expression to my views that the development of fisheries cannot be achieved by isolated effort. Co-operative endeavour is absolutely essential not only among fishermen but even more so among official departments, both of the provinces and the centre. Only thus will duplication of effort be avoided and needless expenditure of funds prevented.

Not only the centre but the provinces are devoting today more attention than at any time in the past to the development of fisheries as part of their drive to stimulate the output of foodstuffs. Hence it is more than ever necessary that the various Fisheries Departments must work in unison, if the final results are to be of a lasting character.

The picture which I have sketched before you, is, I realize, far from complete, but is the best that I could do under the circumstances. I believe I shall be failing

Conclusion.

in the performance of a most obvious duty if I were not to express my grateful thanks to the Council of the National Institute of Science of India, for their bestowal of the Chandra Kala Hora Memorial Medal on me. While I appreciate the distinction conferred on me, I feel that the honour rightly belonged to the fishermen without whose enthusiastic co-operation, my task would have been well nigh impossible. They, and not I, ought to have been the real recipient of the award. It would also be unbecoming on my part if I were not to refer to the need of praise and credit due to my staff, both technical and clerical, without whose attentiveness the Fisheries Department might not have achieved the little it has done.

A word more before I have done and that is to express my grateful appreciation of the generosity of Dr. and Mrs. S. L. Hora, whose munificent liberality and devotion to the cause of scientific advancement have made possible the institution of the award. Dr. Hora is justly reputed as a trojan in the realm of zoological research. He has

shown the true breadth of vision of a scientist in the wide and elastic terms governing the award. Wisely, the use of the term development has been defined to include 'all aspects of biological, technological and sociological studies, including the improvement of fishing nets and craft and the betterment of the social and economic condition of the fishermen.' But for the generous phraseology of this condition, the honour I have received would never have come my way.

EXPLANATION OF PLATES.

Plate IX.

FIG. 1.—The 'Shelmari', an ordinary 22 feet sailing craft, equipped in 1934 with a 22 B.H.P. engine by the Burmah Shell Oil Storage and Distribution Co. (India) Ltd. to demonstrate to the fishermen the potentialities of power vessel to transport fish.

FIG. 2.—The 'Hashimi', a 112 feet twin-screw vessel equipped with two national superior engines, each developing 250 B.H.P., built at a cost of Rs.1,00,000 for wartime services is now used for fish transport. She made the trip from Bombay to Ormara, off Baluchistan in about 70 hours.

The two figures on this plate illustrate how from a small beginning has developed today's impressive fishing fleet of Bombay comprising 50 powered vessels.

Plate X.

FIG. 1.—A view of the Sassoon Dock at Bombay.

It is for all practical purposes the focal point of the city's fish trade. Here, a launch, soon after docking, is boarded by swarms of wholesale buyers, eager to clinch bargains and rush supplies for retail sale in the city's markets.

FIG. 2.—Selling fish by numbers.

Trayful of mackerels being counted in scores by four men, one at each corner of the tray, where there is a triangular partition into which one fish is thrown as each score is removed. The number of fish in the triangular partitions gives the number of scores removed.

FIG. 3.—An improved type of fishing craft, equipped with 22½ B.H.P. marine diesel engine (mast and sail not seen) built by the Bombay Fisheries Department for sale to fishermen on subsidy-cum-loan basis.

Each boat is 45 feet in length, 11.5 feet broad and 5 feet deep.

FIG. 4.—The 'Tapase', the latest addition to the fishing fleet, has been in operation for a little over two years.

Plate XI.

FIG. 1.—A close-up view of a modern Fish Curing Yard.

The picture shows an overhead reservoir, a well and section of the Curing Yard.

FIG. 2.—'Somnathprashad', a 72 footer motor launch, fitted with twin gray marine diesel engine, each developing 250 B.H.P., owned by the Binga Fisheries Co-operative Society and used for the transport and marketing of the catches of its members.

The cost of the launch was Rs.40,000 of which Rs.10,000 was granted as subsidy and Rs. 30,000 as loan to the Society by the Government of Bombay.

Plate XII.

FIG. 1.—A view of the middle jetty at Sassoon Dock with two sheds constructed by the Port Trust, Bombay. The bulk of city's fish trade is conducted under these sheds.

FIG. 2.—An old type of Fish Curing Yard comprising a row of thatched huts where fish are cured on the bare mud floor.

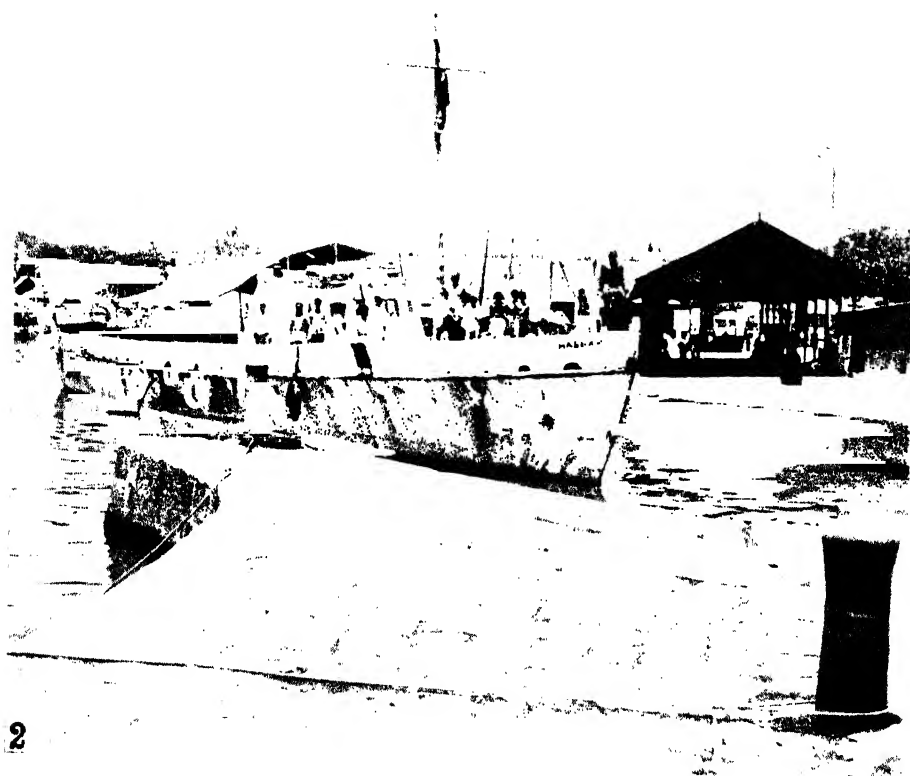
FIG. 3.—A modern Fish Curing Shed with cement concrete platforms to replace mud floors.

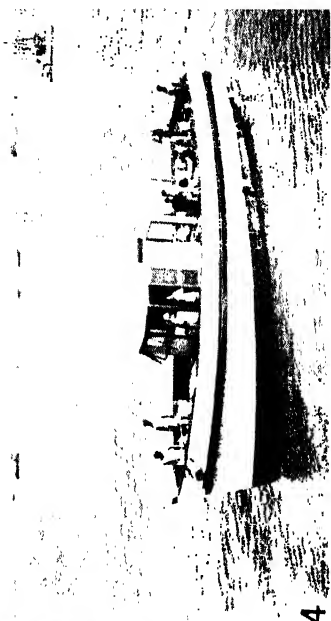
The Government of Bombay have earmarked Rs.9,00,000 for the improvement of 34 Fish Curing Yards in the State.

Statement of the Fish carrying Vessels in service along the Bombay Coast.

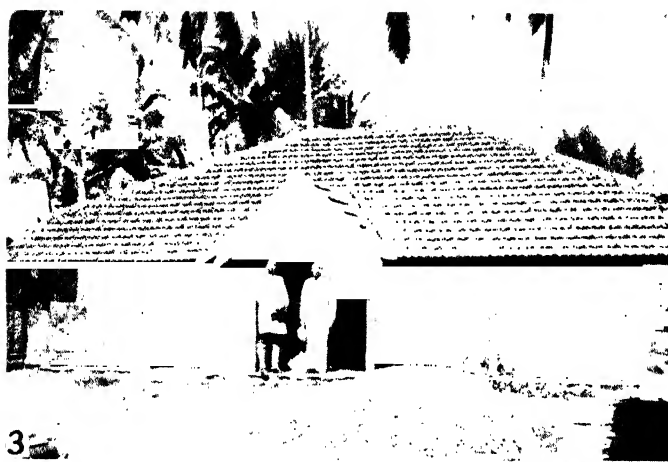
S. No.	Name of the vessel.	Owner.	Approx. cost Rs.	B.H.P.	Tonnage.
1	2	3	4	5	6
1	Sir Frederick Sykes	India Fisheries Ltd., Sassoon Dock, Colaba, Bombay	13,000	28.50	4.93
2	Lady Brabourne	Ditto	20,000	52.50	8.99
3	Lord Brabourne	Ditto	23,000	58	7.83
4	Karim	Janjira Fishing Co., Sassoon Dock, Colaba, Bombay	13,000	40	12.14
5	Chand Tara	Abubakar Hussein Sahib Thakur, Fish Merchant, Sassoon Dock, Bombay.	18,000	52	9.74
6	New Noor-e-Mohammadi	Ditto	40,000	52	19.21
7	Sitara	Ditto	50,000	165	12.60
8	Ruparel	India Fisheries Ltd., Sassoon Dock, Colaba, Bombay	40,000	100	14.6
9	Mackerel Queen	Ditto	40,000	165	9.95
10	Lady Colville	Ditto	50,000	165	6.60
11	Jahangir	Ditto	60,000	165	109.96
12	Razaki	Janjira Fishing Co., Sassoon Dock, Colaba, Bombay	30,000	75	19.09
13	Gajanan Prasad	Konkan Fishing & Trading Co., Sassoon Dock, Colaba, Bombay.	30,000	100	14.25
14	Diamond Jubilee	A. Karmally, Esq., Coastal Fisheries Ltd., Yusuf Bldg., 4th floor, R. No. 37(B), Opp. Flora Fountain, Fort, Bombay.	80,000	165	26.56
15	Divali	New Malwan Fisheries Co., Sassoon Dock, Colaba, Bombay.	75,000	165	36.47
16	Sultania	Sultania Trading Co., Madina Mansion, Near Crawford Market, Bombay.	50,000	110	9.45
17	Madina	A. H. Thakur, Esq., Fish Merchant, Sassoon Dock, Colaba, Bombay.	60,000	110	13.70
18	Dhan Prasad	Valimohamed Alimohamed & Co., Machhi Bazar, Sewri, Bombay 15.	20,000	40	11.53
19	M.F.V. 'Vijaylaxmi'	Ditto	24,000	60 Atlantic	25.35
20	M.F.V. Palar Shaw	Western Fisheries Co., Mherwan Bldg., Sir P. M. Road, Fort, Bombay.	80,000	165	39.15
21	M.F.V. 947-Vijaylaxmi	Sansare Fishing Co., Sassoon Dock, Colaba, Bombay	24,000	60 Atlantic	25.35
22	M.F.V. Somnath Prasad	Binga Fisheries Co-operative Society, Binga, Taluka Karwar, Dist. N. Kanara.	45,000	500 Twine Grey Marine.	48.56
23	M.F.V. King Fisher	Abdul Soomarr Shrivji, c/o K. S. Shivji & Co., 141-146, Chakla St., Bombay No. 3.	28,000	60	20.96
24	M.F.V. Shahjahan	A. H. Thakur, Esq., Fish Merchant, Sassoon Dock, Colaba, Bombay.	60,000	500	21.30
25	Ram Leela	The Konkan Fishing Co., Sassoon Dock, Bombay	35,000	160 Grey Marine	14.25
26	Laxmi	Parker Navigation Co., Sassoon Dock, Colaba, Bombay	25,000	200 B.H.P. 6 cylinder Grey Marine.	23.06

S. No.	Name of the vessel.	Owner.	Approx. cost Rs.	B.H.P.	Tonnage.
1	2	3	4	5	6
27	Saraswati	..	60,000	120 B.H.P. Widop Engine.	29-13
28	Jalanga	..	5,00,000	225 B.H.P. Lorimer Diesel engine.	42-47
29	Tapase	..	66,000	165 Grey Marine	17-73
30	Jaya Bharati	..	27,000	22½ B.H.P. Ruston Marine diesel engine.	11-67
31	Shanta-Durga	..	27,000	Ditto.	11-67
32	Neera ..	..	35,000	225 B.H.P. Grey Marine Engine.	40 (Regd.)
33	Vitha ..	..	35,000	Do. Diesel.	13-03
34	Jyoti ..	..	1,35,000	96 B.H.P. Grey Marine Engine.	15-22
35	M.F.V. Chandraprabha	..	35,000	255 B.H.P. Grey Marine Engine.	14-55
36	Hashemi	..	1,00,000	National Superior diesel engines 2, each 250 B.H.P.	58-52
37	Chandrika	..	2,00,000	200 B.H.P.	39-29
38	Jalprasad	..	50,000	83 H.P.	12-09
39	Nalin ..	..	50,000	160 B.H.P. Black-stone heavy duty engine.	25-92
40	Arvind	..	50,000	Ditto.	25-92
41	Kumud	..	50,000	Ditto.	25-92
42	Pushkar	..	50,000	Ditto.	25-92
43	Neela ..	..	35,000	24 B.H.P. Gardner Marine Engine.	6-17
44	Bhadur	..	22,000	216 Grey Marine Engine.	13-03
45	Shamaprasad	..	40,000	225 Grey Marine Engine.	25-94
46	Fides ..	..	70,000	110 B.H.P.	20-00
47	Ganga Sagar	..	13,000	23 B.H.P. Lister Marine Engine.	4-97
48	Bombay Duck	..	34,000	45 B.H.P. Two Ruston Marine Engine.	5-67









IN VIVO STUDIES ON THE 'ANTI-THIAMINE FACTOR' IN FRESHWATER MUSSEL (*LAMELLIDENS MARGINALIS*).

By K. K. REDDI, I.C.I. Research Fellow, Department of Biochemistry, Indian Institute of Science, Bangalore.

(Communicated by Dr. B. C. Guha, F.N.I.)

(Received December 30, 1949; after revision February 8; read March 3, 1950.)

INTRODUCTION.

The occurrence of 'anti-thiamine factor' in certain species of fish was first reported by Green (1936, 1937) and his associates (1940, 1941, 1942). The enzymic nature of the factor was established by Spitzer *et al.* (1941), Woolley (1941), Sealock *et al.* (1931) and Sealock and Goodland (1944). The nature of the action of this factor on thiamine was established by Krampitz and Woolley (1944) by the isolation of pyrimidine and thiazole derivatives following the hydrolytic cleavage of the vitamin.

Recently it was reported by Reddi *et al.* (1948) that the visceral mass of freshwater mussel (*Lamellidens marginalis*) contains an active enzyme system which destroys thiamine. Experimental evidence was presented to show that the enzyme system is composed of two thiaminases, one optimally active at pH 3.6 and the other at pH 6.5. The two thiaminases were separated and their kinetics were studied (Reddi *et al.* 1949).

The present communication deals with the study of the influence of the thiaminase system in freshwater mussel on the availability of added thiamine to rats. It is well known, the factors that render the ingested enzymes ineffective either by destruction or inactivation, are present in the gastro-intestinal tract. Therefore, this direct study on the rats will be of more practical value.

EXPERIMENTAL.

Young albino rats were used for these experiments. The growth promoting property of vitamin B₁ is applied as the criterion of the availability.

Basal diet (free from vitamin B₁).—Evans and Lepkovsky (1929) studied about seven diets containing various amounts of sucrose, proteins and fat. Of all the diets tested, the most sensitive for growth studies was found to be a sucrose-protein diet of the following composition:—

Composition of the basal diet.

Casein (free from vitamin B ₁) ..	..	20
Sucrose ..	..	70
Salt mixture ..	..	4
Autoclaved yeast ..	..	10

This diet was supplemented with two drops of Shark liver oil daily.

Preparation of casein free from vitamin B₁.—The casein was prepared according to the method of Evans and Lepkovsky (*loc. cit.*).

Autoclaved Yeast.—Whole dried yeast was spread in pans to a depth of less than one inch and autoclaved for 5 hours at 18–20 pounds pressure. This preparation was used as a source of the thermostable water-soluble factor throughout the experiment.

Salt mixture (McCollum).—Sodium chloride 51.0; Crystals of magnesium sulphate, 159.6; monobasic sodium phosphate 104.1; monobasic calcium phosphate, 162.0; dibasic potassium phosphate, 286.2; ferric citrate 35.4 and calcium lactate 390.0.

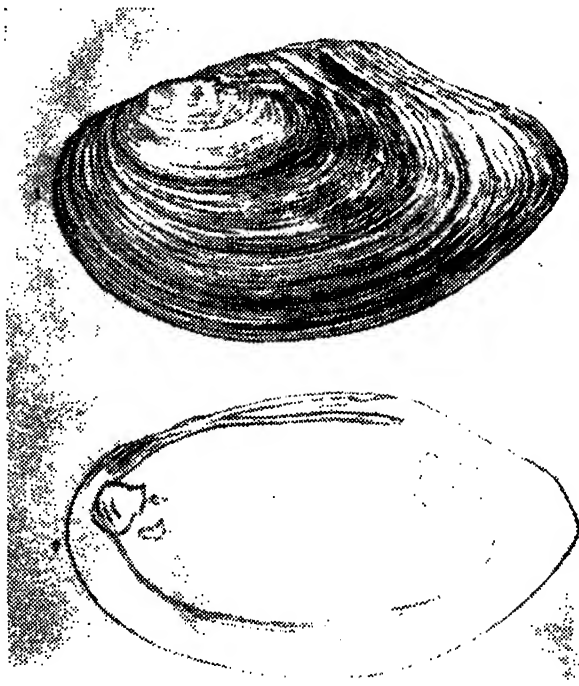


FIG. I.—1. *Lamellidens marginalis*.
2. Muscular scars and pallial impression of same.

Preparation of the mussel extract.—The mussels were obtained fresh and the shells were removed. The whole visceral mass (100 gm.) was minced and ground with water (400 c.c.). The suspension was allowed to stand overnight in a refrigerator. It was then filtered through cloth. The turbid aqueous extract was purified by acidification. To the turbid extract 5*N* acetic acid was added drop by drop with stirring till the pH of the extract was 4.0. This was kept in the ice chest for one hour for complete precipitation. At the end of the period, it was filtered in cold through Whatman No. 5 filter paper under suction with the help of hyflo-supercel. The clear filtrate contains both the thiaminases. The extract was prepared fresh every week.

Procedure.—Eighteen young albino rats, 4 weeks old, weighing from 40–50 gms. and of known nutritional history were used as experimental animals. These were placed in individual cages provided with raised wide mesh bottoms, to prevent the animals to have access to excreta. The storage capacity of the rat for vitamin B₁ is so low that it is not necessary to deplete the animal preliminary to feeding (Evans and Lepkovsky, 1928). However, they were fed on basal diet for seven days to be on the safe side. During this period there was a rapid increase in the weight of all

animals. At the end of this period, they were assembled into three groups, each group having six animals.

Group I .. Basal diet + 5 micrograms thiamine hydrochloride.

Group II .. Basal diet + 5 micrograms thiamine hydrochloride + 2 c.c. mussel extract.

Group III .. Basal diet only (control).

10 gm. of basal diet per day per rat was given. Thiamine in solution, 5 micrograms per rat per day, which approximates the growth requirement (Williams and Spies, 1939) was delivered through pipette into mouth. Rats in Group II, received 2 c.c. of mussel extract per day. Before giving the regular diet, the mussel extract was given in small cups, with a pinch of sugar. After it was licked completely, 5 micrograms of vitamin B₁ in solution was given orally.

The observations of body weight were made once in five days.

Rats in Group I, receiving 5 micrograms of vitamin B₁ steadily gained in weight, thereby indicating that the amount of vitamin given is quite sufficient for normal growth.

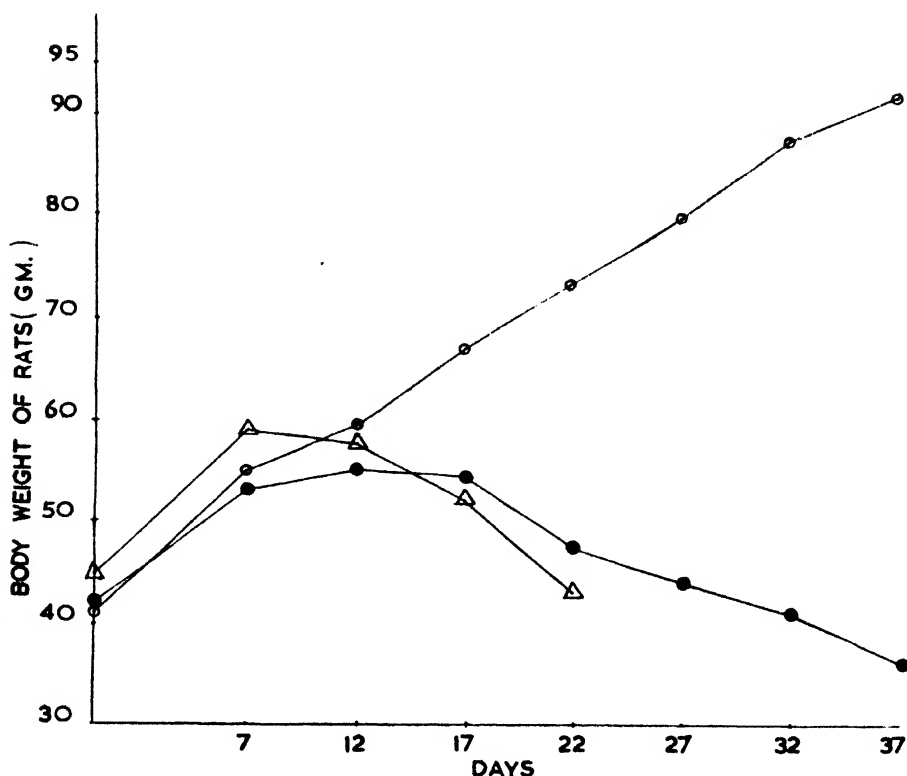


Fig II. Influence Of Mussel Extract On The Thiamine Availability

- — Basal Diet + 5 Micrograms Thiamine Hydrochloride
- △—△ — Basal Diet + 5 Micrograms Thiamine Hydrochloride + 2 cc Mussel Extract.
- — Basal Diet (Control)

Rats in Group II, receiving 2 c.c. of mussel extract along with 5 micrograms of vitamin B₁, rapidly declined in weight and their food intake had also fallen down. By about 20th day, severe symptoms of vitamin B₁ deficiency, such as lack of muscular co-ordination, spasticity, retraction of head and paralysis of hind legs were noticed. Spinning the rat by its tail evoked convulsive seizures. Five animals in this group died by 25th day and the rest died by 28th day.

The animals on basal diet (control group) lost weight gradually and the food intake had also fallen down. But the symptoms of deficiency, such as torpidity and spastic movements were noticed only after four weeks. Two rats died on 34th day and the rest were alive till 37th day, when the experiment was discontinued.

The results are presented in Figure II.

DISCUSSION.

It seems obvious from the results that the 'anti-thiamine factor' present in the mussel extract is capable of destroying vitamin B₁, both *in vitro* (Reddi *et al.*, 1948) and *in vivo*. These results are of practical importance, since the 'anti-thiamine factor' is reported to be widely distributed in foodstuffs of both plant and animal origin. According to Joliffe (1943), this factor represents a type of conditioning factor potentially responsible for malnutrition.

The destructive effect of this factor can find application in the biological assay of vitamin B₁. It can be used in preparing diets free from vitamin B₁. It is difficult and time consuming to prepare diets free from vitamin B₁ for biological assay. Autoclaving or sulphite treatment might involve partial or complete destruction of other essential factors. It is far simpler and more effective to incubate the material, that is to be rendered free from vitamin B₁, with mussel extract. Abderhalden (1946) studied the application of thiaminase in biological experiments. Symptoms of deficiency were quickly produced in pigeons given carp flesh, which contains thiaminase.

SUMMARY.

The influence of mussel extract on the availability of added thiamine hydrochloride was studied by rat growth technique. The results indicate that the factor present in mussel extract is capable of destroying thiamine in the system.

The application of the 'anti-thiamine factor' in the mussel extract in biological assays of vitamin B₁ has been discussed.

ACKNOWLEDGMENT.

I am very grateful to Mr. B. N. Banerjee, Professor-in-charge, Department of Biochemistry, for his active interest and helpful suggestions during the course of this investigation and to the Council of National Institute of Sciences for the award of an Imperial Chemical Industries Research Fellowship.

REFERENCES.

- Abderhalden, E. (1946). Neuer Weg Zum Studium Von Avitaminosen. *Arch. Neerl. Physiol.*, **28**, 373.
- Evans, M. H. and Lepkovsky, S. (1928). Sparing action of fat on the anti-neuritic vitamin. *Science*, **28**, 298.
- Evans, M. H. and Lepkovsky, S. (1929). The Technique for determination of the Anti-neuritic vitamin B₁. *J. Nutrition*, **2**, 1.
- (1936). Chastek paralysis.—A new disease of foxes. *Minnesota Wild life disease investigation*. (U.S. Dept. Agri.), **2**, 106.
- Green, R. G. (1937). Chastek paralysis.—Minnesota Wild life disease investigation. *University of Minnesota and Minnesota Department of Conservation*, **3**, 83.
- Green, R. G. and Evans, C. A. (1940). A deficiency disease of foxes. *Science*, **92**, 154.
- Green, R. G., Carlson, W. E. and Evans, C. A. (1941). A deficiency disease of foxes produced by feeding fish. *J. Nutrition*, **21**, 243.

- Green, R. G., Carlson, W. E. and Evans, C. A. (1942). The inactivation of vitamin B₁ in diets containing whole fish. *Ibid.*, **23**, 165.
- Joliffe, N. (1943). Conditioned malnutrition. *J. Amer. Med. Assn.*, **122**, 299.
- Krampitz, L. O. and Woolley, D. W. (1944). The manner of inactivation of thiamine by fish tissue. *J. Biol. Chem.*, **152**, 9.
- Reddi, K. K., Giri, K. V. and Das, R. (1948). Thiaminase system in freshwater mussel (*Lamellidens marginalis*). *Enzymologia*, **12**, 238.
- Reddi, K. K. and Giri, K. V. (1949). Purification and separation of the two thiaminases in freshwater mussel. (*Lamellidens marginalis*), *Ibid.*, **13**, 281.
- Sealock, R. R., Livermore, A. H. and Evans, C. A. (1943). Thiamine inactivation by the fresh fish or Chastek paralysis factor. *J. Amer. Chem. Soc.*, **65**, 935.
- Sealock, R. R. and Goodland, R. L. (1944). Thiamine inactivation by the Chastek paralysis factor. Inhibition of thiamine inactivation. *Ibid.*, **66**, 507.
- Spitzer, E. H., Coombes, A. I., Elvehjem, C. A. and Wisnicky, W. (1941). Inactivation of vitamin B₁ by raw fish. *Proc. Soc. Expt. Biol. Med.*, **48**, 376.
- Williams, R. R. and Spies, T. D. (1939). Vitamin B₁ and its use in medicine, McMillan & Co., 313.
- Woolley, D. W. (1941). Destruction of thiamine by a substance in certain fish. *J. Biol. Chem.*, **141**, 997.

DETERMINATION OF ELASTIC CONSTANTS OF SOLIDS BY PULSE METHOD.

By KRISHNAJI, M.Sc., Department of Physics, University of Allahabad.

(Communicated by Dr. D. S. Kothari, D.Sc., F.N.I.)

(Received July 6 ; read August 5, 1949.)

INTRODUCTION.

One of the most interesting applications of ultrasonics is the determination of elastic constants of solids and determination of the velocity of the two types of elastic waves in them. It is also possible now to study the phenomenon of interference in solid plates and to use the results for determining refractive indices of solids for ultrasonic waves. Some fifty years ago Prof. C. G. Knott (1899) had shown that whenever a wave—say a plane longitudinal one—is incident upon the interface of a liquid and an isotropic solid, it gives rise to three waves, viz. (i) a reflected longitudinal wave in the liquid itself, (ii) a refracted longitudinal wave in the solid, and (iii) a refracted shear wave in the solid; all of them travelling with different velocities. The situation is shown diagrammatically in Fig. 1 where θ is

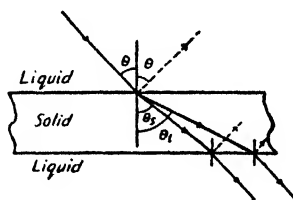


FIG. 1.

the angle of reflection of (i), θ_l is the angle of refraction for (ii) and θ_s is the angle of refraction for (iii). He has developed the theory of propagation of these waves and has further calculated the energies of the reflected and refracted waves for various angles of incidence. A short summary of Knott's (1899) theory applicable to the case of 'longitudinal wave incident from a fluid and falling upon an elastic solid', is appended here for ready reference.

The equations of motion for plane waves in an elastic solid are expressible in the form

$$(m+n)\nabla^2\phi = \rho \frac{d^2\phi}{dt^2} \quad \dots \quad (1)$$

$$n\nabla^2\psi = \rho \frac{d^2\psi}{dt^2} \quad \dots \quad (2)$$

$$n\nabla^2\zeta = \rho \frac{d^2\zeta}{dt^2} \quad \dots \quad (3)$$

where the plane XY is taken perpendicular to the wave front, the displacement in directions X, Y, Z are

$$\xi = \frac{\partial \phi}{\partial x} + \frac{\partial \psi}{\partial y}, \quad \eta = \frac{\partial \phi}{\partial y} - \frac{\partial \psi}{\partial x}, \quad \zeta = \zeta \quad \dots \quad (4)$$

and ρ is the density, n the rigidity and $m - \frac{1}{3}n = k$ called the bulk modulus.

The stress components are

$$\left. \begin{aligned} P &= (m+n) \nabla^2 \phi - 2n \frac{\partial \eta}{\partial y}, & S &= n \frac{\partial \xi}{\partial y} \\ Q &= (m+n) \nabla^2 \phi - 2n \frac{\partial \xi}{\partial x}, & T &= n \frac{\partial \xi}{\partial x} \\ R &= (m-n) \nabla^2 \phi, & U &= n \left(2 \frac{\partial^2 \phi}{\partial x \partial y} + \frac{\partial^2 \psi}{\partial y^2} - \frac{\partial^2 \psi}{\partial x^2} \right) \end{aligned} \right\} \quad \dots \quad (5)$$

The waves of the ϕ type are longitudinal travelling with the velocity

$$V_l = \sqrt{\frac{m+n}{\rho}} = \sqrt{\frac{E(1-\mu)}{(1+\mu)(1-2\mu)\rho}} \quad \dots \quad (6)$$

Where E is the Young's modulus of elasticity and μ is the Poisson's ratio given by the expression

$$\mu = \left[\frac{k^2 - 2}{2(k^2 - 1)} \right], \text{ where } k = \frac{V_l}{V_s}, \quad \dots \quad (7)$$

the waves of the ψ type are shear waves travelling with the velocity

$$V_s = \sqrt{\frac{\eta}{\rho}} \quad \dots \quad (8)$$

Let us now consider a specific case of plane waves travelling in a fluid medium and incident upon a solid surface. The surface of separation being defined by the plane $x = 0$. It can be easily seen that (assuming that no ψ waves exist in the liquid; and taking ϕ of the form $Ae^{ib(cx+y+wt)}$) the solution is of the form

$$\left. \begin{aligned} \phi &= Ae^{ib(cx+y+wt)} + A_1 e^{ib(-cx+y+wt)} \\ \text{in the liquid medium characterized by the constants } m_1, n_1 \text{ and } \rho_1 \\ \phi' &= A' e^{ib(c'x+y+wt)} \\ \psi' &= B' e^{ib(\gamma'x+y+wt)} \end{aligned} \right\} \quad \dots \quad (9)$$

refracted waves in the solid medium having constants m_2, n_2 and ρ_2 where A is the amplitude of incident longitudinal wave

A_1	„	„	„	reflected	„	„
A'	„	„	„	refracted	„	„
B'	„	„	„	shear	„	„
c	„	cotangent	θ			
c'	„	„	θ_1			
γ'	„	„	θ_s			

Now the following boundary conditions have to be satisfied at the interface :—

- (1) The displacement normal to the surface must be same in both the media.
- (2) The tangential displacement must be the same in both the media.
- (3) The normal stresses must be equal in both the media.
- (4) The tangential stresses must be equal in both the media.

Condition (1) wants

$$\frac{\partial \phi}{\partial x} = \frac{\partial \phi'}{\partial x} + \frac{\partial \psi'}{\partial y}$$

which on substitution from (9) gives

$$c(A - A_1) = A'c' + B'$$

or

$$cY = A'c' + B' \quad \dots \quad \dots \quad \dots \quad (10)$$

where

$$Y = A - A_1.$$

Since it has been assumed that no shear waves exist in liquid, condition (2) need not be considered.

Condition (3) gives in substitution from (5)

$$\frac{\rho_1}{\rho_2} (\gamma'^2 + 1)X = A'(\gamma'^2 - 1) + 2B'\gamma' \quad \dots \quad \dots \quad \dots \quad (11)$$

where

$$X = A + A_1.$$

Condition (4) gives on substitution from (5)

$$B'(\gamma'^2 - 1) - 2A'c' = 0. \quad \dots \quad \dots \quad \dots \quad (12)$$

Equations (10), (11), and (12) give on simplification

$$\left. \begin{aligned} Y &= \frac{c'}{c} \frac{\gamma'^2 + 1}{\gamma'^2 - 1} A' \\ X &= \frac{\rho_2}{\rho_1} A' \left[\frac{\gamma'^2 - 1}{\gamma'^2 + 1} + \frac{4c'\gamma'}{\gamma'^4 - 1} \right] \\ B' &= \frac{2c'}{\gamma'^2 - 1} A' \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (13)$$

We can easily see that knowledge of the velocities of the various types of elastic waves can enable us to evaluate the elastic constants of solids by equations (6), (7) and (8) and that amplitudes of the reflected and refracted waves of the two types can be predicted by equations (13). The energy fractions of different waves can be subsequently calculated from the Knott's energy equation

$$\left. \begin{aligned} 1 &= A_1^2 + \frac{\rho_2 c' A'^2}{\rho_1 c} + \frac{\rho_2 \gamma' B'^2}{\rho_1 c} \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (13)'$$

or

$$1 = E_1 + E_2 + E_3$$

where E_1 , E_2 , E_3 denote energies of reflected, refracted longitudinal and refracted shear waves taking the incident energy as unity.

Methods for finding V_l and V_s for opaque solids were first suggested by Bär and Walti (1934) and Bez Bardilli (1935). They have been recently used by Schneider and Burton (1949) for studying the elastic constants of aluminium, copper and several types of resins. The method is based on the phenomenon of total reflection. A longitudinal ultrasonic wave is incident on a plane parallel plate of a solid suspended in a liquid bath. The angle of incidence of the beam is changed by rotating the plate about the vertical axis. The energy transmitted through the plate is noted for increasing angle of incidence. Since the velocity of the waves in the solid is normally greater than in the liquid the waves are refracted away from the normal

(Fig. 1) and therefore at a critical angle of incidence θ_1 the longitudinal wave is totally reflected showing a pronounced minimum in the transmitted energy. Again at another angle θ_2 the shear wave is also totally reflected showing zero transmission of sound energy. At these angles the following well-known relations hold good :

$$V_l = \frac{V}{\sin \theta_1}, \quad \dots \dots \dots (14)$$

and

$$V_s = \frac{V}{\sin \theta_2}, \quad \dots \dots \dots (15)$$

where V is the velocity of the longitudinal wave in the liquid. Thus by experimentally finding the values of θ_1 and θ_2 we can know V_l and V_s and using them calculate the values of the elastic constants of the solid.

The possibilities and importance of ultrasonic methods have been greatly enhanced by the use of pulse technique developed largely during the last War. The pulse technique is the latest and most powerful method. The results obtained by this method may be regarded as physically equivalent to those obtained by continuous methods, since it may be shown that differences in behaviour between pulsed sound and continuous sound in liquids should produce negligible effects. Pellam and Galt (1946) have used this technique for measurement of velocity and attenuation of ultrasonic waves in liquids. This paper is divided into two sections; first giving an account of the measurement of the elastic constants of aluminium, brass, iron and a specimen of black stone from Malabar (South India); the second section gives the calculated energies of reflected and refracted waves based on equations (13) and (13)' for the cases of water-iron and water-malabar stone using the results obtained in the first section. We have, however, postponed the consideration of absorption coefficient and the experimental verification of the results calculated in the second section of this paper for another occasion.

SECTION I.

Apparatus and method.

Fig. 2 shows the block diagram of the apparatus used. An accurately controlled linear saw-tooth oscillator is used to trigger an electronic radio-frequency pulse generator (1948). The transmitter generates a short radio-frequency pulse of 2.5 mc./sec. repeated at the frequency of the saw-tooth time base oscillator. The

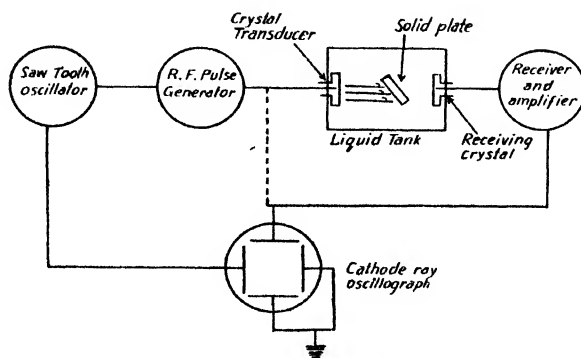


FIG. 2

electrical energy is converted to ultrasonic energy by applying the electrical pulse across a 2.5 mc./sec. X-cut quartz disc contained in a special mount. The transmitter disc is fitted into a specially constructed tank (shown in Fig. 3) which contains the liquid. On the other side of the tank a similar quartz disc is placed which acts as the receiver, i.e., voltage is developed across it when ultrasonic energy falls on it. In the middle of the tank the solid plate is suspended by a specially designed holder. It can be rotated about the vertical axis and the rotation can be measured on the graduated circular dial. Special care is taken to keep the faces of the transmitting and receiving crystal and the solid plate parallel. The output of the receiving crystal is fed to a pulse receiver and amplifier. The equipment is used in conjunction with a cathode ray oscillograph which enables visual or photographic observation. The output of the receiver is applied to the vertical deflection plates of the C.R.O. A portion of the transmitter output is also applied to the same set of plates. To the horizontal plates is applied the saw-tooth time base voltage. When the equipment is switched on we see a pattern as shown in Fig. 4, on the screen. The first vertical pip is due to the transmitter pulse and the second is due to the pulse received by the receiving crystal, the pulse having travelled through the liquid and the solid plate.

The general procedure is to note the height of the second pip or the voltage as the solid plate is rotated, i.e., the angle of incidence is changed. Graphs of amplitude of the pulse passed through the plate and the angle of incidence is plotted for various substances. Photographs of the oscillograph screen is also taken at various angles of incidence.

Observations and Results.

Figures 4, 5 and 6 are photographs showing the pip height for the case of aluminium at zero incidence, when longitudinal wave is totally reflected and when shear wave is totally reflected respectively. Note the complete absence of the second pip in Fig. 6. Figures 7 to 10 are photographs for the case of iron plate at four angles of incidence. Fig. 8 is for the case when longitudinal wave is totally reflected whereas Fig. 10 is for the case when shear wave is also reflected. Figs. 7 and 9 show the interesting phenomenon of multiple reflection between the plate and the receiving electrode. Note the decreasing height of the successive pulses. This will be studied later on and will be utilized to find the attenuation coefficient.

Figures 11 to 16 show the graphs of amplitude of the pulse passed through the plate vs. angle of incidence for various substances. The graphs are self-explanatory. The tank liquid in all the cases was distilled dust-free water.

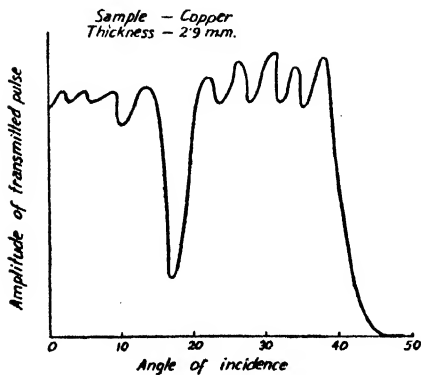


FIG. 11.

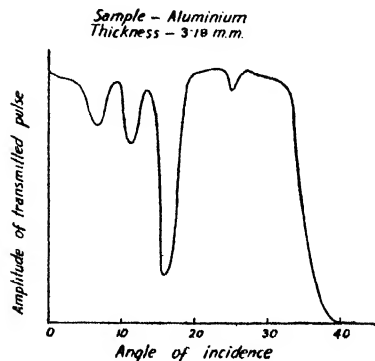


FIG. 12.

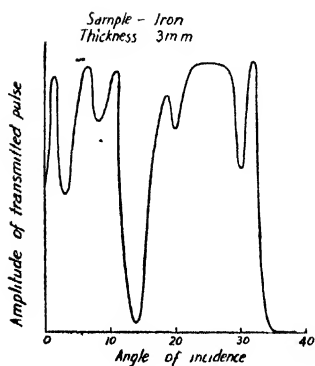


FIG. 13.

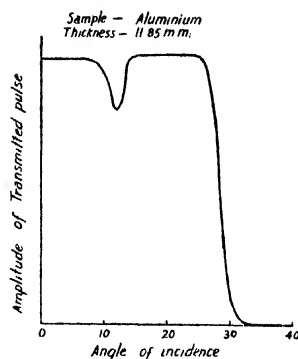


FIG. 14.

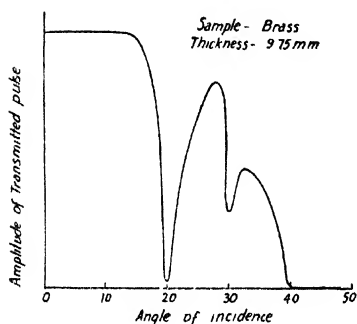


FIG. 15.

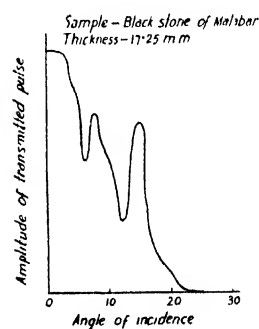


FIG. 16.

It is seen that as expected results obtained from thin plates are low whereas thicker plates (at least a few wavelengths thick) give correct results. The results obtained from these graphs are tabulated in Table I. It is to be noted that in the case of the specimen of black stone from Malabar the shear velocity is larger than in metal.

TABLE I

No.	Substance	Density	Tank Liquid	V cm./sec.	V_l cm./sec.	V_s cm./sec.	η dynes/cm. ²	E dynes/cm. ²	μ
1	Aluminium	2.70	Water	1.5×10^6	7.12×10^5	2.83×10^5	2.16×10^{11}	6.09×10^{11}	0.406
2	Brass	8.54	„	„	4.5×10^5	2.33×10^5	4.64×10^{11}	1.22×10^{12}	0.317
3	Iron	7.86	„	„	6.1×10^5	2.85×10^5	6.38×10^{11}	1.78×10^{12}	0.361
4	Black stone from Malabar	2.99	„	„	7.23×10^5	3.84×10^5	4.41×10^{11}	1.15×10^{12}	0.303

SECTION II.

This section gives the calculated values of the energies of the reflected and re-fracted waves based on equations (13). Table II shows the data for the case of water and iron and the Table III shows the data for the case of water and malabar stone.

TABLE II.
Water to Iron.

θ	E	E_1	θ_1	E_2	θ_s	E_3
0°	1	0.8928	0°	0.1004	0°	0.0000
5°	1	0.8728	20°44'	0.1313	9°32'	0.0059
10°	1	0.8868	44°48'	0.0925	19°15'	0.0207
12°	1	0.8953	57°35'	0.0804	23°17'	0.0245
14°	1	0.9239	79°5'	0.0587	27°22'	0.0124
16°	1	0.8485	....	Does not exist	31°39'	0.150 7
18°	1	0.8165	....	„	35°57'	0.2006
20°	1	0.8550	....	„	40°32'	0.1410
30°	1	0.8041	....	„	71°48'	0.1959

TABLE III.
Water to Malabar Stone.

θ	E	E_1	θ_1	E_2	θ_s	E_3
0°	1	0.7586	0°	0.2421	0°	0.0000
5°	1	0.7566	24°51'	0.2180	12°54'	0.0254
10°	1	0.7636	56°47'	0.1514	26°23'	0.0849
12°	1	0.9759	....	Does not exist	32°9'	0.0151
14°	1	0.6451	....	„	38°15'	0.3549
16°	1	0.6802	....	„	44°52'	0.3198
18°	1	0.7104	....	„	52°17'	0.2991
22°	1	0.7989	....	„	73°32'	0.1986

The experimental verification to these data will be undertaken shortly.

In conclusion I wish to express my sincere thanks to Dr. R. N. Ghosh, D.Sc., F.N.I., F.A.S., under whose careful guidance this work has been conducted.

REFERENCES.

- Bar, R. and Walti, A. (1934). Determination of Poisson's Ratio by Ultrasonic vibrations. *Helv. Phys. Acta*, **7**, 7, 658.
- Bez-Bardili, W. (1935). Über ein Ultraschall-Totalreflektometer zur Messung von Schallgeschwindigkeiten sowie der elastischen konstanten fester Körper. *Zeitschrift Für Physik*, **96**, 761.
- Glasoe and Lebacqz (1948). Pulse Generators (Radiation Lab. Series McGraw Hill Book Co.).
- Knot, C. G. (1899). Reflexion and Refraction of Elastic waves with seismological Applications. *Phil. Mag. and Jour. of Science*, **48**, 64.
- Pellam, J. R. and Galt, J. K. (1946). Ultrasonic propagation in Liquids. Application of Pulse Technique to velocity and Absorption Measurements at 15 Megacycles. *Jour. Chemical Physics*, **14**, 608.
- Schneider, W. C., and Burton, C. J. (1949). Determination of the Elastic constants of Solids by ultrasonic methods. *Jour. Applied Physics*, **20**, 48.

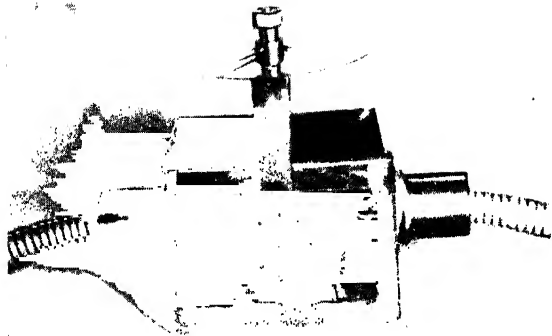


FIG. 3.

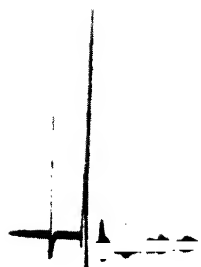


FIG. 4.

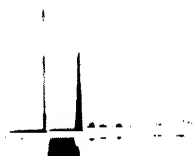


FIG. 5.

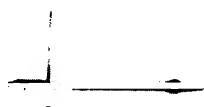


FIG. 6.

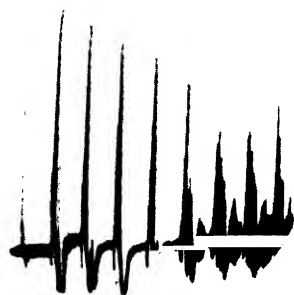


FIG. 7.



FIG. 8.

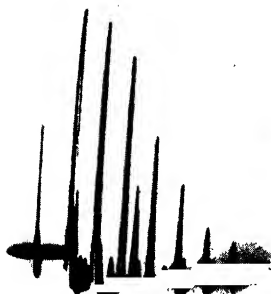


FIG. 9.



FIG. 10.

ELASTIC CONSTANTS OF SOME CUBIC NITRATES.

By J. BHIMASENACHAR, *D.Sc., N.I.S. Senior Research Fellow*

and

T. SESHAGIRI RAO, *B.Sc. (Hons.), Department of Physics, Andhra University, Waltair.*

(Communicated by Prof. S. Bhagavantam, F.N.I.)

(Received September 19; read October 7, 1949.)

1. INTRODUCTION.

For the past several years, this Laboratory has been engaged in investigations relating to crystal elasticity. The starting point for these studies was the development of a new method known as the wedge method (Bhagavantam and Bhimasenachar, 1944) which permits us to handle small crystals. This method has been applied to several single crystals and rocks. Recently, a study of the elastic constants of the isomorphous series of alums has been made by Sundara Rao (1947 and 1948). In continuation of this work, a study of the elastic behaviour of the isomorphous series of nitrates of barium, lead and strontium has been undertaken by the authors and the results are given in the present paper.

2. STRUCTURE AND FORM OF NITRATES.

The nitrates of barium, lead and strontium, belong to the cubic system. It is not yet established decisively whether they belong to the space group T' or T_h^6 . The crystallographic, the spectrographic and the X-ray investigations give results which do not agree with one another. Early crystallographic investigations (Groth, 1908) indicate that they belong to the class T' , while the X-ray data (Wyckoff, 1931) confirm the space group T_h^6 and reveal that these nitrates are cubic with four molecules in the unit cell, the edges a_0 of the unit cube being: barium nitrate 8.11 A.U., lead nitrate 7.84 A.U., strontium nitrate 7.81 A.U.

The powder data show that the nitrate ion is not planar while the Raman effect data (Padmanabhan, 1948) show that it is planar.

This difference, however, does not affect the elastic measurements, since the number of independent elastic constants for all crystal classes in the cubic system is three.

Single crystals about 1 to 1.5 cm. long and broad and about 1 cm. thick were grown from aqueous solutions by slow evaporation. The predominantly developed faces on these crystals were (001) and (111). From these crystals sections parallel to (001) and (111) were prepared by grinding the crystals on a ground glass plate using water as lubricant.

3. DETERMINATION OF THE ELASTIC CONSTANTS.

Sections parallel to the well developed faces (001) and (111) have been employed for a determination of the velocity of propagation of the longitudinal or shear waves along directions perpendicular to the above faces. If f_l or f_t is the fundamental of natural frequency of thickness longitudinal or thickness shear vibrations of a

crystal plate of thickness d then the velocity of propagation of longitudinal or shear waves along the thickness of the plate is given by $v_l = 2df_l$ and $v_t = 2df_t$. These velocities are related with the elastic constants C_{11} , C_{12} and C_{44} through the solutions of Christoffel's equations for propagation of sound along these directions; $v^2\rho = C'$ where ρ is the density and C' is the effective longitudinal or shear constant of elasticity. These solutions are included in Tables I, II and III along with other experimental data. The independent elastic constants C_{11} , C_{12} and C_{44} are calculated from these relations.

TABLE I.
Measurements on Barium Nitrate.
Density = 3.240 gm./cm.³.

Plate No.	Thickness mm.	Section.	Transmission fundamental Mcs.	Mode.	C' Expression.	Value.
1	1.585	(001)	1.356	L^*	C_{11}	5.99†
			0.601	T	C_{44}	1.18
2	1.096	(001)	1.940	L	C_{11}	5.86
			0.896	T	C_{44}	1.23
3	2.033	(111)	0.949	L	$\frac{C_{11} + 2C_{12} + 4C_{44}}{3}$	4.82
			0.570	T	$\frac{C_{11} - C_{12} + C_{44}}{3}$	1.74
4	1.093	(111)	1.772	L	$\frac{C_{11} + 2C_{12} + 4C_{44}}{3}$	4.86
			1.064	T	$\frac{C_{11} - C_{12} + C_{44}}{3}$	1.75

From the above readings, we have $C_{11} = 5.93$, $C_{12} = 1.89$ and $C_{44} = 1.21$ as average values.

TABLE II.
Measurements on Lead Nitrate.
Density = 4.525 gm./cm.³

Plate No.	Thickness in mm.	Section.	Transmission fundamental Mcs.	Mode.	C' Expression.	Value.
1	2.160	(001)	0.740	L	C_{11}	4.62
			0.400	T	C_{44}	1.35
2	1.970	(001)	0.807	L	C_{11}	4.58
			0.442	T	C_{44}	1.37
3	1.453	(001)	1.084	L	C_{11}	4.49
			0.602	T	C_{44}	1.39
4	1.705	(111)	1.014	L	$\frac{C_{11} + 2C_{12} + 4C_{44}}{3}$	5.41
			0.440	T	$\frac{C_{11} - C_{12} + C_{44}}{3}$	1.02
5	1.560	(111)	1.116	L	$\frac{C_{11} + 2C_{12} + 4C_{44}}{3}$	5.48
			0.455	T	$\frac{C_{11} - C_{12} + C_{44}}{3}$	0.91

* Here and in subsequent Tables L —Longitudinal, T —Torsional.

† Here and in subsequent Tables the values of C_{11} , C_{12} and C_{44} are given in units of 10^{11} dynes per sq. cm.

From the above readings the elastic constants for lead nitrate are $C_{11} = 4.56$; $C_{12} = 3.09$; $C_{44} = 1.37$.

TABLE III.

Measurements on Strontium Nitrate.

Density = 3.023 gm./cm.³

Plate No.	Thickness in mm.	Section.	Transmission fundamental Mes.	Mode.	C'' Expression.	Value.
1	1.893	(001)	1.042	<i>L</i>	C_{11}	4.70
			0.574	<i>T</i>	C_{44}	1.43
2	1.880	(001)	1.067	<i>L</i>	C_{11}	4.87
			0.579	<i>T</i>	C_{44}	1.43
3	1.350	(001)	1.470	<i>L</i>	C_{11}	4.76
			0.882	<i>T</i>	C_{44}	1.49
4	1.204	(001)	1.620	<i>L</i>	C_{11}	4.60
			0.923	<i>T</i>	C_{44}	1.49
5	1.917	(111)	1.061	<i>L</i>	$\frac{(C_{11} + 2C_{12} + 4C_{44})}{3}$	5.00
			0.547	<i>T</i>	$\frac{(C_{11} - C_{12} + C_{44})}{3}$	1.33
6	1.867	(111)	1.084	<i>L</i>	$\frac{(C_{11} + 2C_{12} + 4C_{44})}{3}$	4.95
			0.566	<i>T</i>	$\frac{(C_{11} - C_{12} + C_{44})}{3}$	1.35

From these readings, the elastic constants of strontium nitrate obtained are

$$C_{11} = 4.73; C_{12} = 2.18 \text{ and } C_{44} = 1.46.$$

The values of the elastic constants of the nitrates are collected together and presented in Table IV. The last column gives the Bulk modulus k calculated from the relation,

$$k = \frac{C_{11} + 2C_{12}}{3}.$$

TABLE IV.

Elastic Constants of Cubic Nitrates.

	Density.	C_{11}	C_{12}	C_{44}	k
Lead Nitrate ..	4.525	4.56	3.09	1.37	3.580
Barium Nitrate ..	3.240	5.93	1.89	1.21	3.237
Strontium Nitrate ..	3.023	4.73	2.18	1.46	3.030

4. DISCUSSION OF RESULTS.

The elastic constants of barium nitrate have been determined by Sundara Rao (1948) previously in this Laboratory. His values are $C_{11} = 6.02$, $C_{12} = 1.86$ and $C_{44} = 1.21$. The author's values given in Table IV are in excellent agreement with these values.

In the case of lead nitrate, no elastic data are available in the literature. These are determined here for the first time.

For strontium nitrate, Bridgmann has given the value of cubic compressibility for compressed powder-cake. This value is taken from Landolt-Bornstein Tabellen (1935). The value of Bulk modulus calculated from this data comes out as 3.02×10^{11} dynes/cm.² The elastic constants of strontium nitrate determined by the authors lead to a Bulk modulus of 3.03×10^{11} which compares very well with Bridgmann's value.

In this series of isomorphous substances also the Bulk modulus k increases with density. Since there are only three substances no serious attempt can be made to determine the dependence of the Bulk modulus on density.

5. ELASTICITY SURFACES.

Surfaces of elasticity, one for the bending modulus and the other for the rigidity modulus, the radii vectors in the two cases being proportional to s'_{33} and $2(s'_{44} + s'_{55})$ respectively are drawn for each crystal.

Sections parallel to (001) of the elasticity surfaces of the different crystals are given in Figs. 1, 2 and 3. In order to be able to draw these surfaces the C 's are converted into the s 's using the well-known relations. The values of the elastic coefficients (s 's) for the three crystals are consolidated in Table V for ready reference.

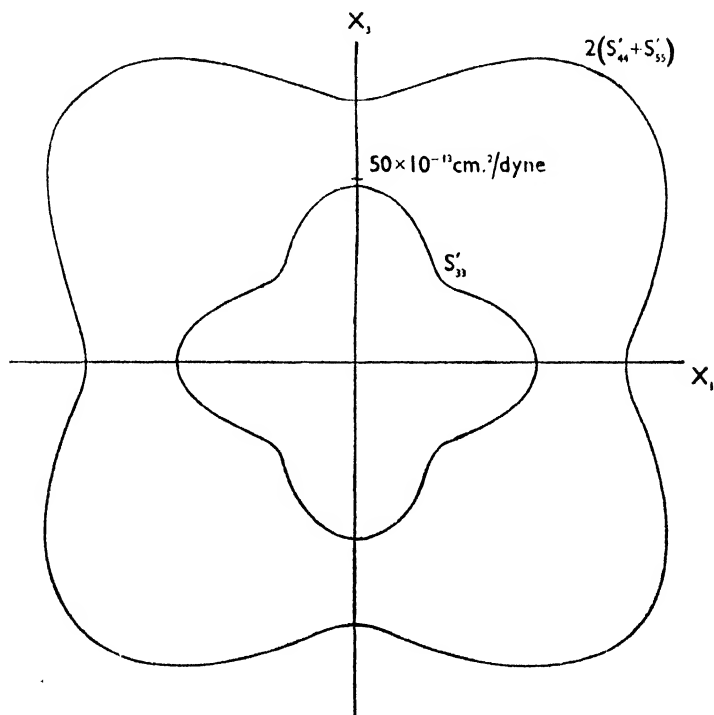


FIG. 1. Sections parallel to (001) of the Elasticity surfaces of Lead Nitrate.

TABLE V.
Elastic Coefficients of the Cubic Nitrates.

	s_{11}	s_{12}	$4s_{44}$
Lead Nitrate ..	49	-20	73
Barium Nitrate ..	20	-5	83
Strontium Nitrate ..	30	-9	69

(Units for s 's in this Table are 10^{-13} cm.²/dyne.)

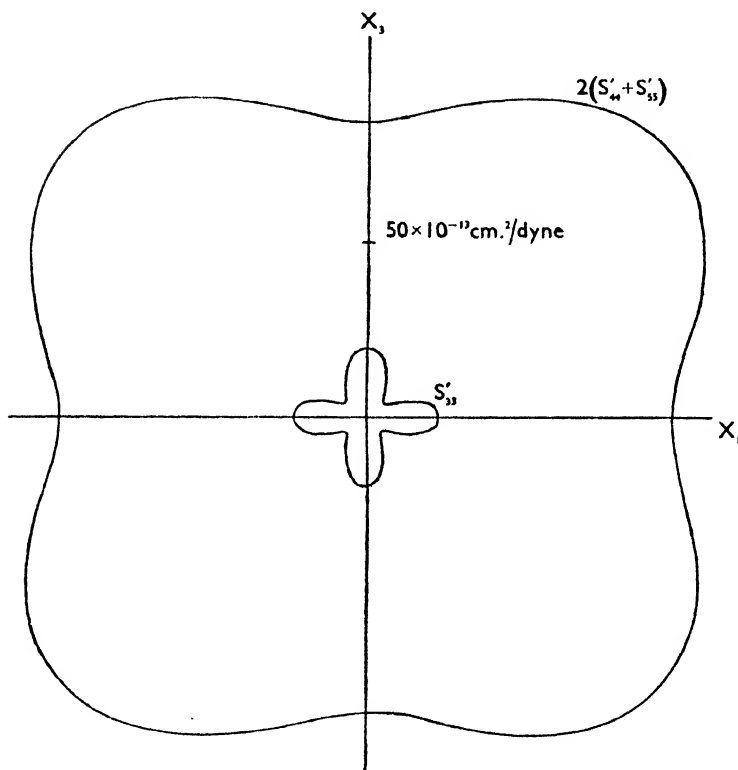


FIG. 2. Sections parallel to (001) of the Elasticity surfaces of Barium Nitrate.

6. SUMMARY.

The elastic constants of single crystals of barium nitrate, strontium nitrate and lead nitrate have been determined employing the wedge method. They are $C_{11} = 5.93$, $C_{12} = 1.89$, $C_{44} = 1.21$ for barium nitrate; $C_{11} = 4.73$, $C_{12} = 2.18$, $C_{44} = 1.46$ for strontium nitrate and $C_{11} = 4.56$, $C_{12} = 3.09$, $C_{44} = 1.37$ for lead nitrate.

The authors take this opportunity to offer their grateful thanks to Prof. S. Bhagavantam, for the kind interest he has taken in the progress of this work.

One of the authors (J. B.) is indebted to the National Institute of Sciences of India for the award of the Senior Research Fellowship which permitted him to carry out these investigations.

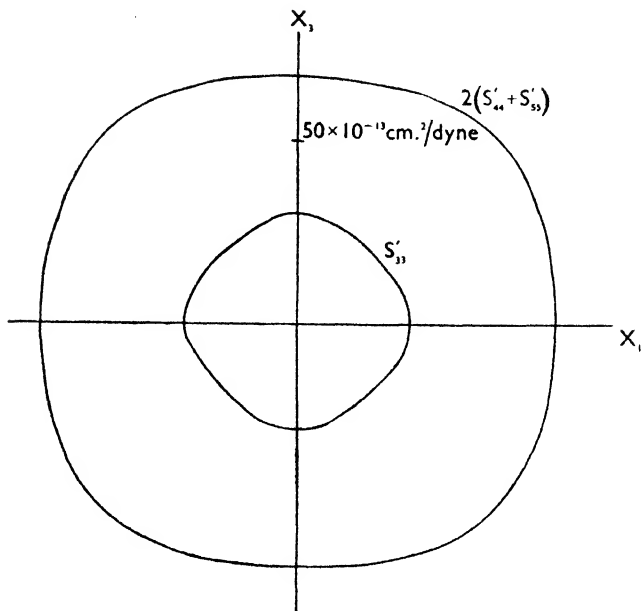


FIG. 3. Sections parallel to (001) of the Elasticity surfaces of Strontium Nitrate.

7. REFERENCES.

- Bhagavantam, S. and Bhimasenachar, J. (1944). Elastic constants of crystals: A new method and its application to Pyrites and Galena. *Proc. Ind. Acad. Sci.*, **20**, 298.
- Groth, P. (1908). *Chemische Kristallographie*, **II**, 103.
- Landolt-Bornstein (1935). *Physikalisch-Chemische Tabellen*. Eg. **IIIa**, 70.
- Padmanabhan, V. M. (1948). *Raman effect in single crystals*. M.Sc. Thesis, Andhra University, 70.
- Sundara Rao, R. V. G. (1947). Elastic constants of Alums and Mixed Alums. *Current Science*, **16**, 91.
- (1948). Elastic constants of Ammonium alum. *Current Science*, **17**, 50.
- (1948). Elastic constants of single crystals of Barium Nitrate. *Current Science*, **17**, 296.
- Wyckoff, R. W. G. (1931). *The Structure of Crystals*, 280.

ELASTIC CONSTANTS OF CORUNDUM.

By J. BHIMASENACHAR, D.Sc., N.I.S. Senior Research Fellow, Department of Physics, Andhra University, Waltair.

(Communicated by Prof. S. Bhagavantam, F.N.I.)

(Received October 13, 1949 ; read March 3, 1950.)

1. INTRODUCTION.

Corundum is an important naturally occurring crystal. It is a highly priced gemstone. Its industrial value as an abrasive is very great as its hardness is next to that of diamond. Therefore it is a substance whose physical properties have been studied very thoroughly. Recently Sundara Rao (1949) has reported the elastic behaviour of a single crystal of synthetic alumina. As this crystal belongs to the D_{3d} class of the trigonal system its elastic behaviour is characterised by 6 independent constants C_{11} , C_{12} , C_{13} , C_{14} , C_{33} and C_{44} . In order to determine these constants 6 independent observations are necessary on crystal plates cut with suitable orientations. In his investigations Sundara Rao has used a synthetic specimen in the form of a semicylindrical boule with the optic axis of the crystal making an angle of about 14° to the axis of the boule. Since natural crystal faces were not developed on this boule he had to use crystal plates cut with odd orientations and was therefore forced to determine the important constant C_{33} by a sum and difference method which invariably magnifies small errors and vitiates accuracy.

Thanks to Prof. C. Mahadevan, M.A., D.Sc., F.A.Sc., F.N.I., the Head of the Geology Department of this University, a natural crystal of good size was available to the author. This crystal was opaque, brownish in colour, about 1" in diameter and 1.5" in length, and had its basal plane (0001) and prism faces (11 $\bar{2}$ 0) well developed. In the present investigation suitable crystal sections were cut from this specimen to an accuracy of less than 1° of arc. Results of investigations on this crystal are presented here.

2. CHOICE OF CRYSTAL SECTIONS.

It has already been said that this crystal has six independent elastic constants and therefore six independent observations are necessary for their determination. Crystal sections employed for this purpose are tabulated in Table I along with the θ , ϕ co-ordinates as well as the values of the direction cosines of the normals to these sections.

The velocities of propagation of longitudinal and shear waves along these normals are determined by the values of C'_{33} and C'_{44} for each particular plate. In general

$$C'_{33} = C_{11}(1 - \alpha_{23}^2)^2 + C_{33}\alpha_{43}^4 + (4C_{44} + 2C_{13})\alpha_{23}^2(1 - \alpha_{23}^2) + 4C_{14}\alpha_{23}\alpha_{33}(3\alpha_{23}^2 - \alpha_{23}^2) \quad \dots \quad (1)$$

$$C'_{44} = C_{11}(\alpha_{12}^2\alpha_{23}^2 + \alpha_{22}^2\alpha_{23}^2) + 2C_{12}\alpha_{12}\alpha_{13}\alpha_{22}\alpha_{23} + 2C_{13}\alpha_{32}\alpha_{33}(\alpha_{12}\alpha_{13} + \alpha_{22}\alpha_{23}) + C_{14}[4\alpha_{12}\alpha_{13}(\alpha_{22}\alpha_{33} + \alpha_{23}\alpha_{32}) + 2(\alpha_{12}^2\alpha_{23}\alpha_{33} + \alpha_{12}^2\alpha_{22}\alpha_{32} - \alpha_{22}^2\alpha_{23}\alpha_{33} - \alpha_{22}^2\alpha_{23}\alpha_{32})] + C_{33}(\alpha_{23}^2\alpha_{33}) + C_{44}[(\alpha_{22}\alpha_{33} + \alpha_{23}\alpha_{32})^2 + (\alpha_{12}\alpha_{33} + \alpha_{13}\alpha_{32})^2] + C_{66}(\alpha_{12}\alpha_{23} + \alpha_{13}\alpha_{22})^2 \quad \dots \quad (2)$$

where the α 's are direction cosines between the three principal axes X_1 , X_2 and X_3 of the crystal and a set of new axes in which the normal to the crystal plate is regarded as the X'_3 axes so that the direction cosines of X'_3 are α_{13} , α_{23} and α_{33} . Particular solutions corresponding to each one of the plates are also given in Table I.

TABLE I.
Description of Crystal Sections.

No.	Cut of the plate.	θ	ϕ	α_{13}	α_{23}	α_{33}	$C'_{33}(L)$	$C'_{44}(T)$
1	Z	0	ϕ	0	0	1	C_{33}	C_{44}
2	X	90°	0	1	0	0	C_{11}	C_{44}, C_{66}
3	Y	90°	90°	0	1	0	C_{11}	C_{44}, C_{66}
4	45° XZ	45°	0°	$\sqrt{\frac{1}{2}}$	0	$\sqrt{\frac{1}{2}}$	$\frac{1}{2}(C_{11} + C_{33} + 4C_{44} + 2C_{13})$	..
5	135° XZ	135°	0°	$\sqrt{\frac{1}{2}}$	0	$-\sqrt{\frac{1}{2}}$	$\frac{1}{2}(C_{11} + C_{33} + 4C_{44} + 2C_{13})$	..
6	45° YZ	45°	90°	0	$\sqrt{\frac{1}{2}}$	$\sqrt{\frac{1}{2}}$	$\frac{1}{2}(C_{11} + C_{33} + 4C_{44} + 2C_{13} - 4C_{14})$	..

(L = Longitudinal; T = Torsional, constants.)

In plates 4, 5 and 6 since the torsions are not observed their solutions are not given. It can be seen from this table that each constant is determined uniquely and there is no need of solving any simultaneous equations.

We may remark even here that Sundara Rao appears to have made, inadvertently, a mistake in describing his plate No. I in his Table I. Direction cosines for this plate must be $\alpha_{13} = 1$, $\alpha_{23} = 0$ and $\alpha_{33} = 0$ if the plate is to lead to determinations of C_{11} , C_{44} and C_{66} . According to his description, his plate I gives $C'_{33} = C_{33}$ and $C'_{44} = C_{44}$.

3. EXPERIMENTAL TECHNIQUE AND RESULTS.

The method employed for determining the normal modes of the crystal sections is the well-known wedge Method (Bhagavantam and Bhimassenachar, 1944) developed in these Laboratories. The driving circuit for the wedge is a variable frequency oscillator rigged up using a Taylor T_{55} valve and operating in the region 2 to 20 Mcs.

Experimental Results are given in Table II.

TABLE II.
Elastic Constants of Corundum.

Density 3.81.

No.	Section.	Thickness in mm.	Frequency in Mcs.	Mode.	Effective Elastic Constant C' .	
					Expression.	Value.
1	Z	2.58	2.356	L	C_{33}	56.3
2	"	2.58	1.515	T	C_{44}	23.2
3	X	2.13	2.588	L	C_{11}	46.3
4	"	2.13	1.833	T	C_{44}	23.2
5	"	2.13	1.569	T	$C_{66} = (\frac{1}{2})(C_{11} - C_{12})$	17.0
6	Y	2.15	2.572	L	C_{11}	46.6
7	"	2.15	1.830	T	C_{44}	23.6
8	"	2.15	1.560	T	$C_{66} = (\frac{1}{2})(C_{11} - C_{12})$	17.1
9	45° XZ	1.67	3.590	L	$\frac{1}{2}(C_{11} + C_{33} + 4C_{44} + 2C_{13})$	54.8
10	135° XZ	2.67	2.250	L	"	54.9
11	45° YZ	1.55	3.494	L	$\frac{1}{2}(C_{11} + C_{33} + 4C_{44} + 2C_{13} - 4C_{14})$	44.7

(As usual C' are expressed in units of 10^{11} dynes/cm.²)

From the above table we have the following average values for the elastic constants.

$$\begin{array}{ll} C_{11} = 46.5 & C_{12} = 12.4 \\ C_{33} = 56.3 & C_{13} = 11.7 \\ C_{44} = 23.3 & C_{14} = 10.1 \end{array}$$

The elastic coefficients or moduli are determined using the usual relations.

$$\begin{array}{ll} s_{11} = 46.5 & s_{12} = -1.05 \\ s_{33} = 1.93 & s_{13} = -0.38 \\ 4s_{44} = 5.77 & 2s_{14} = 1.71 \end{array}$$

Here the s 's are given in Wooster's notation and the units are 10^{-13} cm.²/dyne.

4. DISCUSSION OF RESULTS.

The first thing is to compare our results with those of Sundara Rao ($C_{14} = 46.6$, $C_{33} = 50.6$, $C_{44} = 23.5$, $C_{12} = 12.7$, $C_{13} = 11.7$ and $C_{14} = 9.4$). Excepting for a change in the value of C_{33} the results agree excellently well. As has already been remarked this may be due to the fact that Sundara Rao employs sections with odd orientations and obtains C_{33} by a sum and difference method.

The principal Young's modulus along the optic axis turns out to be 51.8 as against Auerbach's value of 53.1 (*vide* L and B Tables) and leads to a better agreement.

The cubic compressibility β turns out to be 4.11×10^{-13} cm.²/dyne the same as that of Sundara Rao.

5. SUMMARY.

The elastic constants of a single crystal of natural corundum are reported, the values being $C_{11} = 46.5$, $C_{33} = 56.3$, $C_{44} = 23.3$, $C_{12} = 12.4$, $C_{13} = 11.7$ and $C_{14} = 10.1$ in units of 10^{12} dynes/cm.²

The author takes this opportunity to express his gratitude to the National Institute of Sciences of India for the award of a fellowship, to Prof. S. Bhagavantam, Hon. D.Sc., F.A.Sc., F.N.I., for the interest he took in this work and to Prof. C. Mahadevan, M.A., D.Sc., F.A.Sc., F.N.I., for supplying the beautiful specimen of corundum.

6. REFERENCES.

- Bhagavantam, S. and Bhimasenachar, J. (1944). Elastic Constants of Crystals. A New Method and its Application to pyrites and galena. *Proc. Ind. Acad. Sci.*, **20**, 298.
Landolt-Bornstein Tabellen (1923). Physikalisch-Chemische Tabellen. *Hw. I.*, 84.
Sundara Rao, R. V. G. (1949). Elastic Constants of Alumina. *Proc. Ind. Acad. Sci.*, **29**, 352.

AN EMBRYOLOGICAL STUDY OF *LEVENHOOKIA DUBIA* SOND. IN LEHM.

By K. SUBRAMANYAM, *Department of Botany, Central College, Bangalore.**

(Communicated by Prof. P. Maheshwari, D.Sc., F.N.I.)

(Received April 15; read August 4, 1950.)

INTRODUCTION.

The genus *Levenhookia* R.Br. is restricted to South Australia and is placed in the second tribe Styldieae of the family Styldiaceae (Engler, 1908). The earlier literature on the embryological features of the family has already been reviewed by me elsewhere (1950).

MATERIAL AND METHODS.

L. dubia is a slender tiny erect herb growing to a height of one to two inches. The minute flowers are arranged in racemose clusters. The corolla is peculiar in having a grotesque labellum which encloses the column. The material used in this study was collected from a damp pasture land at Melbourne, South Australia, by Mr. J. H. Willis and Mr. O. D. Evans who very kindly passed it on to me for investigation. After following the customary methods for imbedding the material in paraffin, sections were cut at a thickness of 10 to 16 microns and stained in Heidenhain's iron alum-haematoxylin with eosin as a counterstain.

THE FLOWER.

Fig. 1 represents a longitudinal section of the flower to show the arrangement of the different floral parts. The flower is peculiar in having a column which originates from the apex of the inferior ovary and represents the fused style and stamens. The apex of the column ends in a bilobed stigma with one sessile anther on each side of it. The epidermal cells of the stigmatic lobes are papillate and densely cytoplasmic (Fig. 2).

At the base of the column and just above the inferior ovary is the nectary (Figs. 1, 3) composed of glandular cells with conspicuous nuclei and dense contents.

A number of glands are present on the pedicel of the flower, the outer wall of the inferior ovary and the sepals and petals. The mature gland (Fig. 4) consists of a biseriate stalk composed of a variable number of cells and bearing at its apex a group of four cells arranged in a sphere (Figs. 4, 5). The cells of the gland have conspicuous nuclei and dense cytoplasm.

The ovary is rounded to ovoid in outline, inferior and unilocular. The ovules are borne on a massive basal globose free central placenta (Figs. 1, 6). Those toward the upper portion of the placenta are anatropous and those below are hemitropous (Figs. 6, 7). This seems to be related to the breadth of the loculus which is greatest in the upper region but narrows toward the base. The wall of the ovary is made up of five to six layers of cells (Fig. 8). At the mature embryo-sac stage the cells of the innermost layer of the ovary wall become elongated and

* Part of work done during the tenure of a Junior Research Fellowship of the National Institute of Sciences of India.

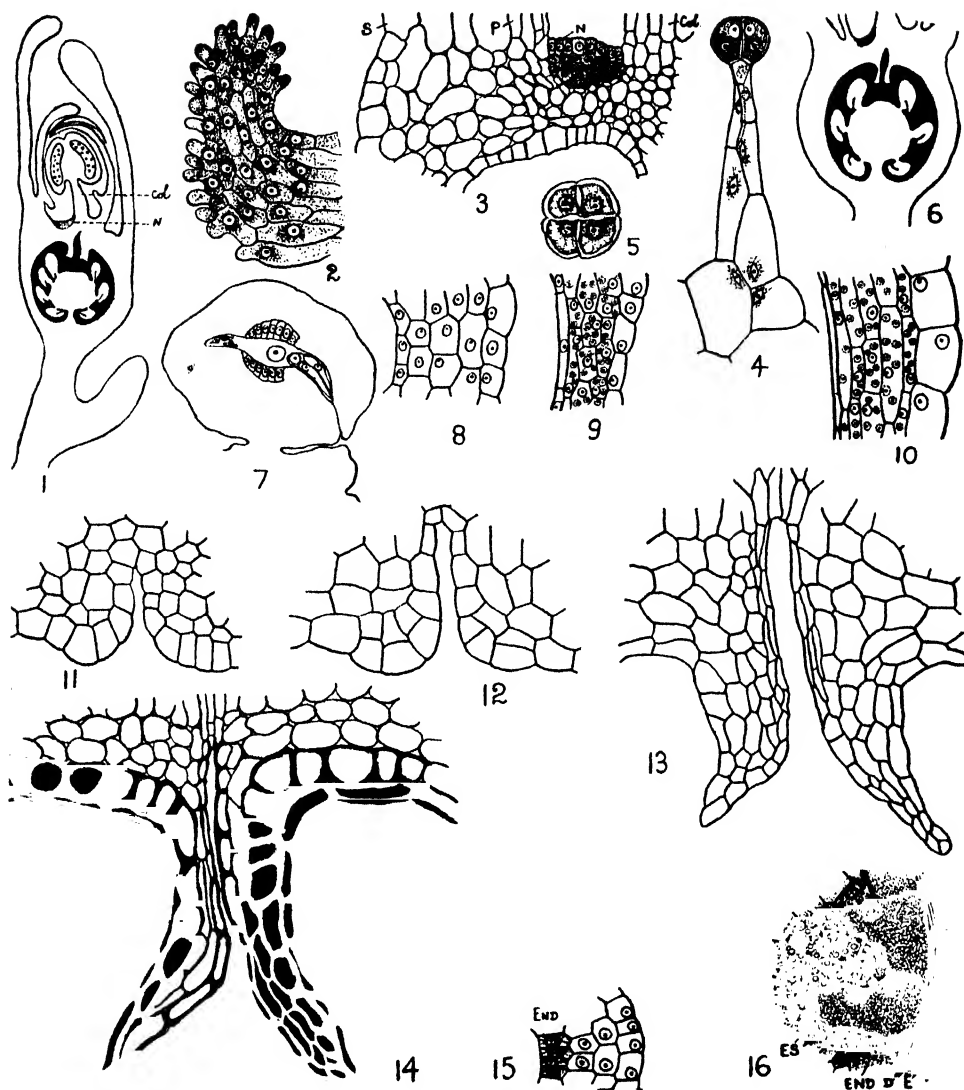


FIG. 1.—L.S. of flower to show arrangement of floral parts (*col.* = column; *n* = nectary). $\times 30$.
 FIG. 2.—A stigmatic lobe with papillose cells. $\times 215$.

FIG. 3.—L.S. nectary (*col.* = column; *n* = nectary; *p* = petals; *s* = sepal). $\times 120$.

FIG. 4.—A multicellular gland. $\times 215$.

FIG. 5.—Top view of gland showing four cells. $\times 400$.

FIG. 6.—L.S. ovary showing free central placentation. $\times 30$.

FIG. 7.—A hemitropous ovule with embryo sac. $\times 215$.

FIGS. 8–10.—Portions of ovary wall at various stages in development of fruit; in later stages the cells of the innermost layer become elongated and lignified. FIG. 8. $\times 291$; FIG. 9. $\times 120$; FIG. 10. $\times 120$.

FIGS. 11–14. Stages in development of process arising from base of column and projecting downward into locule of ovary. FIG. 11. $\times 400$; FIG. 12. $\times 485$; FIG. 13. $\times 291$; FIG. 14. $\times 120$.

FIG. 15.—Portion of integument enlarged (*End.* = *Endothelium*). $\times 400$.

FIG. 16.—Portion of seed coat enlarged (*E* = *epidermis*; *end.* = *endothelium*; *es.* = *endosperm*; *d* = crushed walls of the seed coat.) $\times 215$.

thickened due to a deposition of lignin (Figs. 9, 10). At the same time the cells of the outer epidermis enlarge and a prominent cuticle is deposited over their outer surface.

An interesting feature seen in a longitudinal section of the ovary is the presence of a structure projecting downward from the base of the column and surrounding the apex of free central placenta (Figs. 1, 6). In very young stages the inner wall of the column bordering the apex of the loculus consists of a mass of homogenous cells with a narrow vertical slit in the centre (Fig. 11). A few of the epidermal cells lining the base of the slit undergo periclinal divisions (Fig. 12). By further divisions of these cells and the elongation of the hypodermal cells the projection becomes more pronounced. It presents a forked appearance in a longitudinal section and covers the apex of the free central placenta (Fig. 13). The forks slightly curve outwards and are composed of a mass of thin walled parenchymatous cells. Later, the epidermal cells become elongated and strongly lignified, and the cells of the subepidermal layer, which enlarge prominently, also become strongly thickened (Fig. 14).

A characteristic feature of this plant is the occurrence of starch grains in the ovary wall (Figs. 9, 10), the placenta, the cells of the integument and the endosperm (Figs. 16, 42-47).

MICROSPORANGIUM AND MALE GAMETOPHYTE.

A transverse section through the young anther lobe shows a plate of four archesporial cells (Fig. 17), which divide periclinally to form the primary parietal and the primary sporogenous cells. By further periclinal divisions (Fig. 18) the primary parietal layer produces the anther wall and the sporogenous cells by undergoing a few more divisions become converted into the spore mother cells (Fig. 19). The epidermis is the outermost layer in the anther; next comes the endothecium; then a middle layer which soon becomes flattened and crushed; and finally the glandular tapetum whose cells are uninucleate at first (Fig. 19) but later become binucleate (Fig. 20). The microspore mother cells undergo the usual reduction divisions and form tetrads of microspores. Quadripartition of the microspore mother cells takes place by peripheral cleavage furrows (Fig. 21) and the microspores are arranged tetrahedrally.

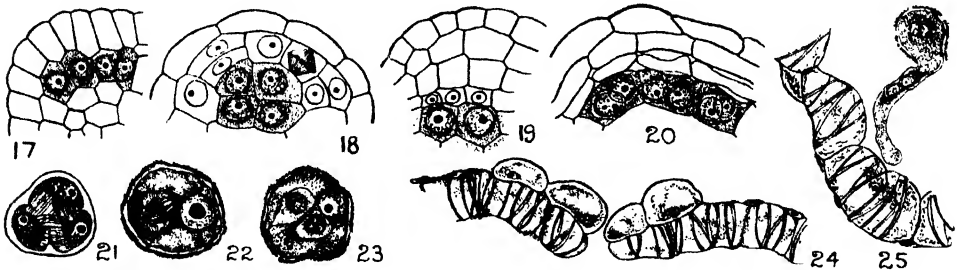


FIG. 17.—Portion of cross-section of anther showing archesporial cells. $\times 679$.

FIG. 18.—Division of primary parietal layer. $\times 679$.

FIG. 19.—Portion of young anther showing epidermis, endothecium, middle layer, uninucleate tapetum and sporogenous cells. $\times 679$.

FIG. 20.—Same at later stage showing binucleate tapetum. $\times 679$.

FIG. 21.—Quadripartition of microspores by formation of cleavage furrows. $\times 970$.

FIG. 22.—Division of generative nucleus. $\times 970$.

FIG. 23.—Mature pollen grain showing tube nucleus and male cells. $\times 970$.

FIG. 24.—Portion of mature anther showing stomium, and fibrous endothecium. $\times 485$.

FIG. 25.—Germination of a pollen grain *in situ*; note male cells in pollen tube. $\times 485$.

In the mature anther the middle layer and the tapetum become disorganized and the endothecium develops the usual fibrous thickenings. The epidermal cells

also become shrivelled except those lying near the line of dehiscence which enlarge conspicuously (Fig. 24) and constitute the stomium.

The first division of the microspore results in the delimitation of a small lenticular generative cell from a large tube cell. The generative cell divides to produce two male cells (Figs. 22, 23).

In many anthers the pollen grains were found to have germinated *in situ*. Fig. 25 shows one such case with the two male cells in the tube. The tube nucleus is still in the pollen grain, and is showing signs of degeneration.

MEGASPORANGIUM AND FEMALE GAMETOPHYTE.

The ovules appear as conical outgrowths on the placenta. The single integument appears just after the differentiation of the hypodermal archesporial cell and is made

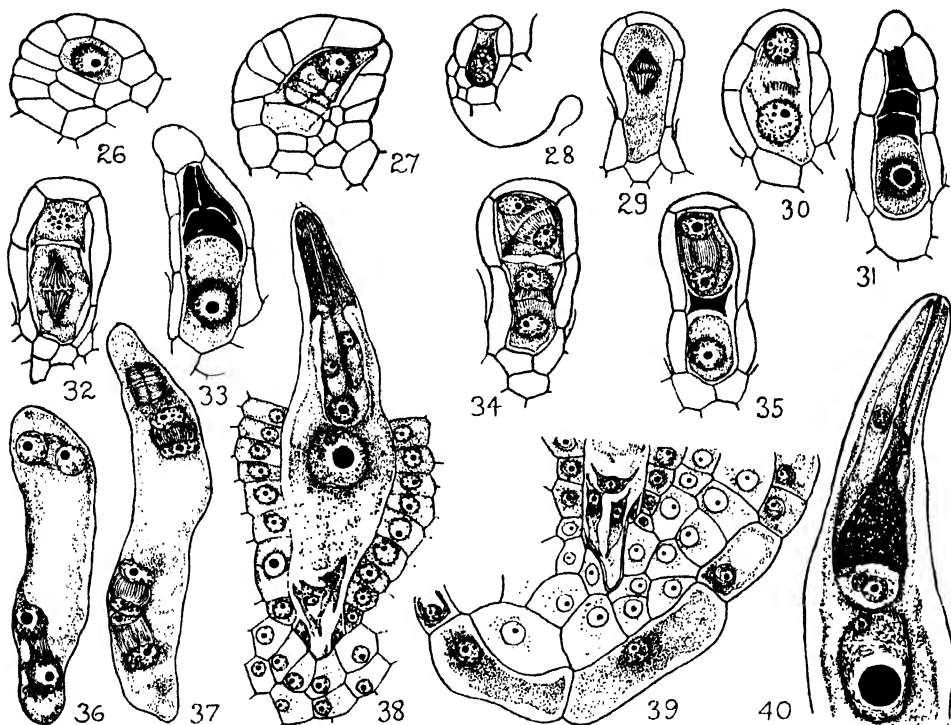


FIG. 26.—L.S. young nucellus showing primary archesporial cell. $\times 1000$.

FIG. 27.—Three archesporial cells arranged in a superposed manner. $\times 800$.

FIG. 28.—Megaspore mother cell. $\times 450$.

FIG. 29.—Megaspore mother cell in division. $\times 679$.

FIG. 30.—Dyad formation. $\times 1000$.

FIG. 31.—Tetrad of megaspores. $\times 1000$.

FIGS. 32-33.—Stages in formation of T-shaped tetrad. FIG. 32. $\times 1000$; FIG. 33. $\times 679$.

FIG. 34.—Dyad cell dividing; note oblique division in upper dyad cell. $\times 1000$.

FIG. 35.—Division in the lower dyad cell completed; upper dyad cell in telophase stage. $\times 1000$.

FIGS. 36-37.—Second and third nuclear divisions in embryo sac. $\times 1000$ each.

FIG. 38.—Mature embryo sac showing elongated synergids and conspicuous endothelium; note filiform apparatus in the synergids. $\times 700$.

FIG. 39.—Basal portion of embryo sac showing small chalazal process, pointed antipodal cells and endothelium. $\times 679$.

FIG. 40.—A stage in double fertilization. $\times 970$.

up of three layers of cells. Later, it becomes four-layered (Fig. 15) except in the region of the micropyle where the number of layers is usually smaller.

The primary archesporial cell (Fig. 26) directly functions as the megaspore mother cell (Fig. 28). Sometimes two to three archesporial cells (Fig. 27) are met with in the same nucellus (cf. *Stylidium garminifolium*, Subramanyam, 1950). As a rule tetrad formation takes place normally (Figs. 29, 30, 31). Sometimes the upper dyad cell divides in a plane at right angles to that of the lower (Figs. 32, 33), or the division is oblique (Fig. 34). Rarely it shows a belated division (Fig. 35). In any case, the chalazal megaspore functions. After undergoing three successive divisions (Figs. 36, 37) it produces an eight-nucleate embryo sac of the Polygonum type (Maheshwari, 1948).

During the further development of the embryo sac, the cells of the nucellar epidermis are completely destroyed, so that the embryo sac comes in contact with the innermost layer of the integument which becomes modified to form the endothelium (Figs. 15, 38). It consists of transversely elongated vacuolate cells with conspicuous nuclei.

The mature embryo sac (Fig. 38) tapers towards both ends. The synergids are longer than in most plants. They have a hooked apical end with a filiform apparatus, and a fairly broad basal end containing a large nucleus. The egg is pear-shaped and is situated between the synergids. The two polar nuclei fuse in the centre of the embryo sac to form a large secondary nucleus just prior to fertilization. The antipodals are organized into definite cells (Figs. 38, 39) and are usually pointed basally. They persist during the early stages of endosperm development (Figs. 41 to 47), but there is a tendency for the lower end of the embryo sac to grow beyond them as a very delicate process (Fig. 39) penetrating into the chalaza.

The pollen tube enters the embryo sac between the synergids (Fig. 40). Double fertilization takes place normally and immediately after the fertilization the synergids shrivel and degenerate.

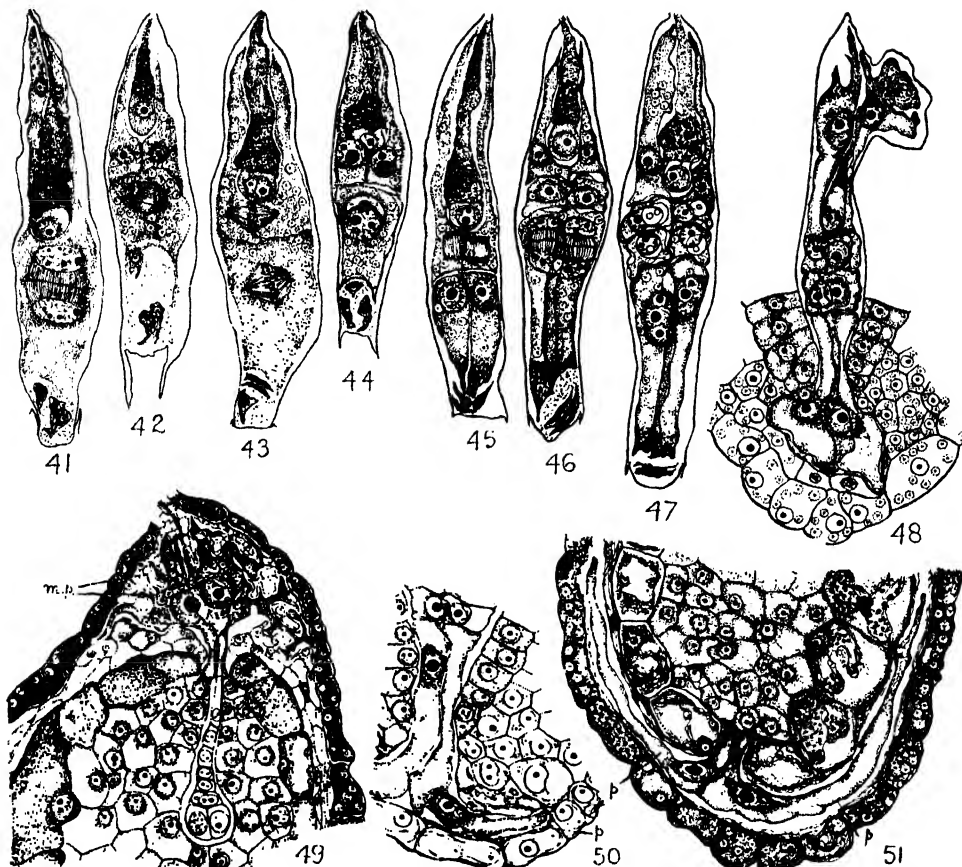
ENDOSPERM.

The primary endosperm nucleus, which lies in the centre of the embryo sac, divides much earlier than the fertilized egg. The first wall is transverse (Fig. 41) followed by a vertical wall in the micropylar and then the chalazal chamber (Fig. 42). Or, the divisions in the two primary chambers are synchronous (Fig. 43). Sometimes the vertical wall in the chalazal chamber is laid down at right angles to that in the micropylar chamber (Fig. 44).

Transverse walls are next formed in each of these two tiers, first in the upper (Fig. 45) and then in the lower (Fig. 46). The result is an eight-celled endosperm made up of four tiers of two cells each.

At the eight-celled stage of the endosperm, the two cells of the upper tier form the micropylar haustorium, and those of the lower form the chalazal haustorium (Fig. 48). The two middle tiers by further divisions form the main body of the endosperm (Fig. 47), which later becomes packed with starch grains (Fig. 16).

Each cell of the micropylar haustorium contains a prominent nucleus embedded in a dense mass of cytoplasm (Fig. 48). It now becomes lodged in a fairly large cavity formed in the micropylar region of the integument by the enormous micropylar growth of the embryo sac. It forms a number of processes penetrating between the cells of the integument at the micropylar region (Fig. 49, *m*, *p*). At the same time the two cells of the chalazal haustorium disorganize the parenchymatous tissue in the chalazal region of the ovule and finally reach the epidermal layer of the seed, where they become distended (Fig. 48) and develop lateral prolongations or protrusions (Figs. 50, 51) which grow in between the cells of the integument.



FIGS. 41-47.—Stages in development of endosperm and differentiation of the micropylar and chalazal haustoria. All. $\times 679$.

FIG. 48.—The young micropylar and chalazal haustoria respectively. $\times 485$.

FIG. 49.—2-celled micropylar haustorium; processes (*m.p.*) from cells of the micropylar haustorium pass into the integument. $\times 291$.

FIG. 50.—Chalazal haustorium at an early stage; note development of the prolongation (*p*) from a cell of the chalazal haustorium. $\times 485$.

FIG. 51.—2-celled chalazal haustorium giving out the prolongations (*p*) which pass up into the integument. $\times 291$.

SEED COAT.

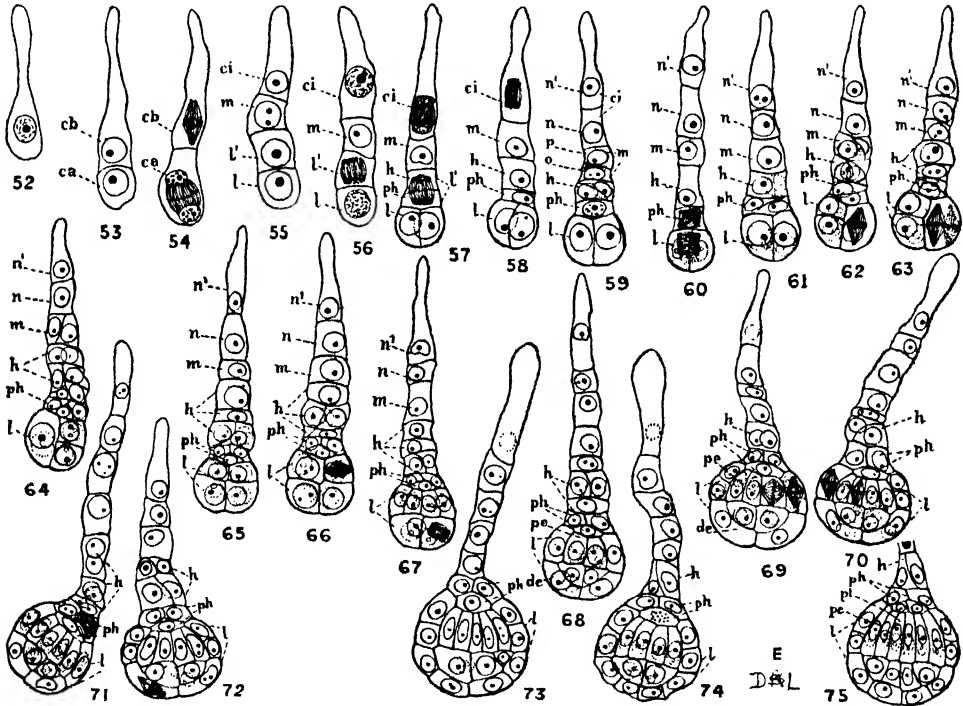
In the mature seed the cells of the outer epidermis and of the endothelium become filled with darkly staining material. Further, the cells of the endothelium enlarge prominently (Fig. 16) and assume an irregular outline. At the same time the middle layers of the integument are more or less completely crushed.

EMBRYO.

The fertilized egg elongates to form a long tubular structure (Fig. 52) and divides by a transverse wall to form two cells *ca* and *cb* (Fig. 53), both of which divide by transverse walls (Fig. 54) to form a filamentous proembryo of four cells *l*, *l'*, *m* and *ci*. Cells *l'* and *ci* divide transversely, either simultaneously (Fig. 57)

or in succession (Fig. 56), producing *ph*, *h*, *n* and *n'* respectively. The cell *l* now divides vertically (Fig. 57) and has the major part mainly in the formation of the embryo. The remaining cells above *l* except *ph*, by further divisions, constitute the filamentous suspensor.

The first division of *l* is followed by the laying down of another vertical wall at right angles to the former resulting in the quadrant stage (Figs. 58–61). The quadrants divide transversely resulting in the octant stage (Figs. 62–65). This is followed by further growth and cell divisions and the differentiation of the three histogens, dermatogen, periblem and plerome (Figs. 66–75).



FIGS. 52-75.—Stages in development of embryo (*ca* = terminal cell of the 2-celled embryo; *cb* = basal cell of 2-celled embryo; *m* and *ci* = cells derived from the basal cell *cb*; *l* = lower daughter cell of *ca*; *l'* = upper daughter cell of *ca*; *ph* and *h* = daughter cells of *l'*; *o* and *p* = daughter cells derived from *m*; *n* and *n'* = daughter cells derived from *ci*; *de* = dermatogen; *pe* = periblem; *pl* = plerome). Figs. 52 to 68. $\times 500$ each; Figs. 69 to 75. $\times 670$ each.

At about the time of the first vertical division in the terminal cell of the pro-embryo, *h* divides obliquely (Fig. 59) or vertically (Fig. 61) forming two cells which undergo transverse and vertical divisions so as to produce a small group of cells (Figs. 62–66). The cell *m* also sometimes divides producing two cells (Figs. 59, 62, 64). As a result of these divisions, the middle portion of the suspensor presents a biseriate appearance (Figs. 62, 64).

At about the quadrant stage of the embryo, *ph* (Fig. 60) divides by an oblique wall (Figs. 60–63) followed by another intersecting oblique wall at the octant stage (Figs. 64, 65) resulting in the formation of a three-celled hypophysis (Figs. 66–73). The outer two cells complete the dermatogen and get more or less merged in this

layer (Figs. 72-75), while the inner cell becomes embedded in the upper portion of the embryo (Figs. 69-73) where it divides vertically (Figs. 74-75) and becomes a part of the plerome.

DISCUSSION.

As is characteristic of Stylidiaceae, the flower of *Levenhookia* has a column with a nectary at its base. In *Stylidium graminifolium* (Subramanyam, 1950) two prominent nectaries are present at the base of the column. Stalked multicellular glands are present on the parts of the flower in both genera.

The ovary is unilocular with a number of ovules borne on a free central placenta. The ovules in the upper region of the placenta are anatropous but those below are hemitropous. This appears to bear some relation to the breadth of the locule which is greatest in the upper region but narrows towards the base. The tendency towards a unilocular condition in the members of this family is very significant since it points the way towards the unilocular ovary of the Compositae. Another interesting feature noticed in a longitudinal section of the ovary of *Levenhookia dubia* is the presence of a rimmed projection hanging from the base of the column into the locule of the ovary.

The development and structure of the microsporangium of *Levenhookia* closely resembles that of *Stylidium*. In many anthers of the former the pollen grains were found to have germinated *in situ* as in *S. graminifolium* (Subramanyam, 1950) and in some members of the closely allied family Lobeliaceae (Kausik and Subramanyam, 1945; Subramanyam, 1949).

The development of the embryo sac conforms to the Polygonum type. The antipodals persist during the early stages of endosperm development. The lower end of the embryo sac grows past them as a very delicate process, penetrating into the chalaza as in *S. graminifolium* (Subramanyam, 1950).

The endosperm is cellular and the course of divisions closely resembles that in *Stylidium* (Rosén, 1935, 1949; Subramanyam, 1950). At the eight-celled stage of the endosperm, the two upper and the two basal cells develop into the micropylar and chalazal haustoria respectively. In later stages the micropylar haustorium gives out lateral processes which grow in between the parenchymatous cells of the integument as in *S. graminifolium* (Subramanyam, 1950). Such a tendency has also been seen in certain members of Orobanchaceae (Crété, 1942; Tiagi, 1950) and Plantaginaceae (Crété, 1942). The two-celled chalazal haustorium develops long tubular prolongations which grow in between the cells of the integument. In *S. graminifolium* (Subramanyam, 1950) the chalazal haustorium is made up of two uninucleate cells and both form a number of processes which grow in between the cells of the integument. In *S. adnatum* and *S. graminifolium* (Rosén, 1935, 1949), however, the chalazal haustorium is not so well developed.

The development of the embryo corresponds broadly to the Solanad type of Johansen (1945). The penultimate cell forms the hypophysis. In *S. graminifolium* (Subramanyam, 1950) the four terminal cells of the filamentous proembryo take part in the formation of the different regions of the embryo.

ACKNOWLEDGMENT.

It gives me great pleasure to thank Prof. P. Maheshwari for his valuable suggestions and for going through the manuscript, Prof. L. N. Rao for encouragement, and the National Institute of Sciences of India for the award of a Research Fellowship. I am grateful to Mr. J. H. Willis of Melbourne and Mr. O. D. Evans of New South Wales, Australia, for supplying me the material used in the present study.

SUMMARY.

The flower has a column formed from the fused style and stamens. A structure projects vertically from the base of the column into the locule of the ovary and becomes thickened in the seed. Multicellular stalked glands of epidermal origin are present on the pedicel and on the surface of the floral parts excepting the column.

The wall of the anther consists of three layers of cells external to the binucleate tapetum. The endothecium shows the usual fibrous thickenings. A stomium is present. The pollen grains are three-celled and frequently germinate *in situ*.

The ovary is inferior and unilocular with a number of unitegmic ovules borne on a basal globose free central placenta. The ovules at the top are anatropous but those at the base are hemitropous. The innermost layer of the integument forms a prominent endothelium. During post-fertilization stages the cells of the innermost layer of the ovary wall become elongated and lignified.

There is usually a single archesporial cell which functions directly as the megaspore mother cell. Occasionally two or three archesporial cells are found. Megasporogenesis proceeds normally and the embryo sac is of the Polygonum type. The synergids are elongated, and show a filiform apparatus and the characteristic hook-like projections. The antipodal cells are pointed at their lower ends and the embryo sac forms a small process which passes beyond them into the chalaza. Double fertilization has been observed.

The endosperm is cellular and follows the Scutellaria type of Schnarf (1931). The micropylar haustorium is two-celled and forms a number of processes penetrating between the cells of the integument at the micropylar region. The two-celled chalazal haustorium develops long tubular prolongations which reach down to the outer epidermis of the seed coat and then grow up in between the cells of the integument.

The development of the embryo has been described in detail. Broadly, it follows the Solanad type of Johansen (1945). The terminal cell of the filamentous procumbent embryo gives rise to the main body of the embryo. The penultimate cell is the hypophysis.

LITERATURE CITED.

- Burns, G. P. (1900). Beiträge zur Kenntnis der Styliaceen. *Flora*, **87**, 313-354.
- Crété, P. (1942). Recherches histologiques et physiologiques sur l'embryologie des Labiati-flores. Contribution à l'étude des formations haustoriales. Diss., Paris.
- Engler, A. (1908). Das Pflanzenreich. Heft 35, Band IV.
- Johansen, D. A. (1945). A critical survey of the present status of plant embryology. *Bot. Rev.*, **11**, 87-107.
- Kausik, S. B. and Subramanyam, K. (1945). A contribution to the embryology of *Lobelia trilobata* Buch.-Ham. *Jour. Indian Bot. Soc.*, **24**, 171-185.
- Maheshwari, P. (1948). The angiosperm embryo sac. *Bot. Rev.*, **14**, 1-56.
- Rosén, W. (1935). Beitrag zur Embryologie der Styliaceen. *Bot. Notiser*, 273-278.
- (1949). Endosperm development in Campanulaceae and closely related families. *Bot. Notiser*, **2**, 137-147.
- Schnarf, K. (1931). Vergleichende Embryologie der Angiospermen. Berlin.
- Subramanyam, K. (1949). An embryological study of *Lobelia pyramidalis* Wall., with special reference to the nutrition of the embryo in the family Lobeliaceae. *New Phytol.*, **48**, 365-373.
- (1950). A morphological study of *Stylidium graminifolium* Swartz. (In press.)
- Tiagi, B. (1950). The embryology of *Cistanche tubulosa* Wt. *Proc. Indian Sci. Cong.*, 27th Session, 48-49.

THE NONLINEAR METHOD OF CIRCUIT ANALYSIS.*

By RAIS AHMED, *Aligarh University.*

(Communicated by Prof. P. S. Gill, F.N.I.)

(Received May 6; read August 4, 1950.)

SUMMARY.

Nonlinear differential equations are being commonly used to express various physical phenomena. Systematic methods of solving such equations have been developed in recent years and they are being applied to problems in physics and engineering. The latest application of nonlinear analysis to vacuum tube circuits has been examined and its limitations discussed.

Nonlinear differential equations are a common phenomenon in the solution of many problems in modern physics and engineering. In the past several years an elaborate method of solving many such equations has been developed both by physicists and mathematicians, and this mathematical tool has been used extensively in the treatment of problems in mechanics, sound and especially electrical engineering. Since the current-voltage relationships in vacuum tubes are nonlinear, an exact analysis of circuits which include vacuum tubes would have to depend on the use of nonlinear differential equations.

One example of the nonlinear differential equation is the famous van der Pol equation for relaxation oscillations:

$$x'' - \mu(1 - x^2)x' + x = 0 \quad \dots \quad (1)$$

The nonlinearity of this equation consists in the fact that the coefficient of x' depends on the value of x itself, and if μ is positive it is clear that this coefficient, which also represents damping in the circuit, will change in sign as x increases from zero to a value greater than one.

Analytic methods of treatment exist for such equations as the van der Pol's, in the case in which μ is small. Attempts have been made to extend these methods to cases in which μ is large (Minorski, 1947), and indeed to more general equations of the type

$$x'' + f(x, x')x' + g(x) = 0 \quad \dots \quad (2)$$

with certain limitations on the functions f and g (Levinson, 1942; Shohat, 1944). However for large μ there is as yet no complete analytic theory comparable to the one that exists for small values of μ .

Since cases with $\mu \gg 1$ are common in unstable circuits (and in many other problems in mechanics), the above-mentioned difficulties led the Soviet physicists L. Mandelstam and N. Papalexi (1935) to develop another approach to this problem (refer to Minorski, 1947 and Kryloff, 1943). This is the so-called Discontinuous Theory of Relaxation Oscillations, and it has already proved very useful in many branches of physics.

* A part of this work was done by the author as contract research for Princeton University, U.S.A., and the guidance of Prof. W. H. Surber is gratefully acknowledged. The author wishes to thank Prof. P. S. Gill for valuable advice and suggestions in furthering the work.

The Discontinuous Theory of Relaxation Oscillations.

The name of this theory signifies the use of mathematical discontinuities to describe rapidly changing dynamical processes during certain time intervals. This mathematical concept of discontinuities has been used in the classical theory of mechanical impacts where, in the infinitesimally small duration of the impact the dynamics of the process is ignored and the pre- and after-impact conditions are correlated on the basis of such general principles as the conservation of energy or momentum. The method makes it possible to understand correctly the overall effect of the impact, although it precludes a study of the process of the impact itself. The discontinuous theory of relaxation oscillations is based on a similar principle and in order to grasp the phenomenon in the large certain local details are necessarily sacrificed.

In this method relaxation oscillations are defined as those 'quasi-discontinuous oscillations in which the rapid changes between certain levels of a physical quantity occur as the result of the loss of a certain internal equilibrium in the system'. Since a rapidly changing process is being represented by an idealization, namely a mathematical discontinuity, it is obvious that the result will be more realistic if the change is more rapid. To approximate this condition in ordinary circuits one may neglect small oscillatory parameters and thereby conveniently reduce the order of the differential equations involved.

The circuit of Fig. 1 may be considered. Assuming that the left-hand branch has no parasitic capacitance and that the right-hand branch has no parasitic

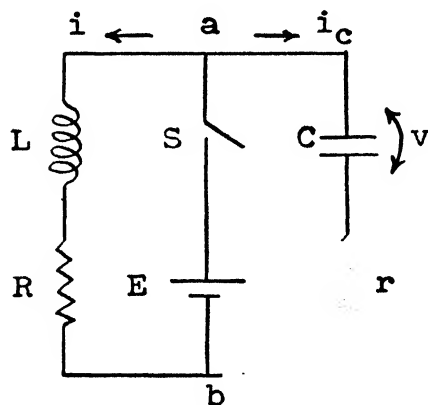


FIG. 1.

inductance and also that the switch S operates instantaneously, the following equations can be written:

$$L \frac{di}{dt} + Ri = E \quad \dots \dots \dots (3)$$

$$rC \frac{dv}{dt} + v = E \quad \dots \dots \dots (4)$$

If the voltage across ab is supposed to have been zero before the instant of switching t_0 and equal to a constant E after t_0 , the solutions of the above differential equations are:

$$i = \frac{E}{R} (1 - e^{-Rt/L}); v = E (1 - e^{-t/rC}) \quad \dots \dots \dots (5)$$

which give

$$\frac{di}{dt} = \frac{E}{L} e^{-Rt/L}; \quad \frac{dv}{dt} = \frac{E}{rC} e^{-t/rC} \quad \dots \quad \dots \quad (6)$$

It is seen that for $t = 0$, the solutions $i(t)$ and $v(t)$ are continuous but that their derivatives experience discontinuous jumps. It may be emphasized that $\frac{di}{dt}$ and $\frac{dv}{dt}$ are represented to have discontinuities only because (1) the time interval during which rapid changes occur is considered to be infinitely short, and (2) the parasitic parameters are neglected making it possible to deal with degenerate equations of the first order instead of the full equations of the second order.

With particular reference to degeneration of a second order differential equation

$$ax'' + bx' + cx = 0 \quad \dots \quad \dots \quad \dots \quad (7)$$

it may be said that on comparison of its solutions (1) when a is small, and (2) when $a = 0$, it is found that although one solution uniformly converges into the other as $a \rightarrow 0$, the derivatives similarly converge only for values of t not in the neighbourhood of $t = 0$. In other words near $t = 0$ the derivatives of the two solutions do not match. It is recognized, therefore, that as a result of certain idealizations, like assuming $a = 0$, or $c = 0$ in the differential equation, discontinuities appear in the mathematical treatment of physical phenomena undergoing rapid changes at certain points of their cycles. In view of the above following definition and basic assumption play a very important rôle in the discontinuous theory of relaxation oscillations.

Definition: Critical points are the points at which the differential equation describing a phenomenon in a certain domain ceases to describe it.

Basic Assumption: If the phenomenon is represented by a curve on a particular plane (like the plane of x and x' , or the plane of currents at two different points in the circuit) and if a locus of critical points is also drawn on the same plane, then whenever the representative point following the curve of the differential equation describing the phenomenon reaches a critical point a discontinuity occurs in the variable of the system.

To illustrate the meaning suppose the system is described by the differential equations

$$x' = \frac{P(x, y)}{R(x, y)} \quad \text{and} \quad y' = \frac{Q(x, y)}{R(x, y)} \quad \dots \quad \dots \quad \dots \quad (8)$$

If (x_c, y_c) is a point such that $R(x_c, y_c) = 0$ then the differential equations become meaningless at that point. Obviously, then $R(x_c, y_c) = 0$ represents the locus of the critical points in this particular case. The curve representing the differential equation itself may be found by eliminating time variations from the above equations. That is,

$$\frac{dy}{dx} = \frac{Q(x, y)}{P(x, y)} \quad \dots \quad \dots \quad \dots \quad \dots \quad (9)$$

represents such a curve or trajectory.

Mandelstam proposed further the application of the principle of conservation of energy to govern the nature of the 'jump' at the discontinuity. This assumption is physically true since it amounts to assuming continuity of current through an inductance or of voltage across a capacitance in electrical circuits.

With this preliminary discussion a study of the multivibrator of Abraham and Bloch (1927) is presented to illustrate the application of the discontinuous theory to relaxation oscillations. This example is taken from N. Minorski's interpretation of the original by A. Andronov and S. Chaiken. It has only been changed in so far as the plate currents of the tubes are considered functions of both the grid and plate voltages, instead of functions of just the grid voltage, as has apparently been

assumed by Andronov and Chaiken. Further, the analysis applies when the grid voltage of neither of the tubes is at or above zero volts.

With reference to Fig. 2 the following equations can be written:

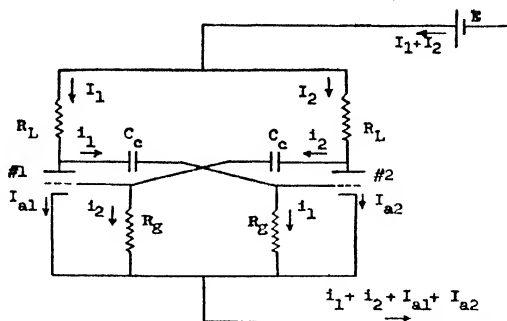


FIG. 2. Symmetrical multivibrator.

$$I_1 = I_{a1} + i_1; \quad I_2 = I_{a2} + i_2$$

$$R_L I_1 + \frac{1}{C_c} \int i_1 dt + R_g i_1 = E; \quad R_L I_2 + \frac{1}{C_c} \int i_2 dt + R_g i_2 = E$$

$$I_{a1} = \theta(e_g, e_p) = \theta(R_g i_2, E - I_1 R_L) \quad \dots \quad (10)$$

$$I_{a2} = \theta(R_g i_1, E - I_2 R_L)$$

From the equation for the tube currents

$$\frac{dI_{a1}}{dt} = R_g \frac{di_2}{dt} \cdot \frac{\partial \theta}{\partial (R_g i_2)} - R_L \frac{dI_1}{dt} \cdot \frac{\partial \theta}{\partial (E - I_1 R_L)} \quad \dots \quad (11)$$

and

$$\frac{dI_{a2}}{dt} = R_g \frac{di_1}{dt} \cdot \frac{\partial \theta}{\partial (R_g i_1)} - R_L \frac{dI_2}{dt} \cdot \frac{\partial \theta}{\partial (E - I_2 R_L)} \quad \dots \quad (12)$$

The following notation may now be introduced *:

$$\frac{\partial \theta}{\partial (R_g i_2)} = \frac{\partial I_{a1}}{\partial (e_{g1})} = g_{m1}; \quad \frac{\partial \theta}{\partial (R_g i_1)} = g_{m2}$$

$$\frac{\partial \theta}{\partial (E - I_1 R_L)} = \frac{\partial I_{a1}}{\partial (e_p)} = \frac{1}{r_{p1}}; \quad \frac{\partial \theta}{\partial (E - I_2 R_L)} = \frac{1}{r_{p2}}$$

The rate of change of tube currents may be expressed:

$$\frac{dI_{a1}}{dt} = R_g \frac{di_2}{dt} g_{m1} - \frac{R_L}{r_{p1}} \cdot \frac{dI_1}{dt} \quad \dots \quad (13)$$

$$\frac{dI_{a2}}{dt} = R_g \frac{di_1}{dt} g_{m2} - \frac{R_L}{r_{p2}} \cdot \frac{dI_2}{dt} \quad \dots \quad (14)$$

* It is to be noted that these partial derivatives correspond to the tube transconductances and plate resistances and are functions of the grid and plate voltages of the tubes.

If I_1 and I_2 are replaced by $I_{a1} + i_1$ and $I_{a2} + i_2$ respectively then

$$\frac{dI_{a1}}{dt} = \frac{R_g \cdot \frac{di_2}{dt} g_{m1} - \frac{R_L}{r_{p1}} \cdot \frac{di_1}{dt}}{1 + \frac{R_L}{r_{p1}}} \quad \dots \quad \dots \quad (15)$$

and

$$\frac{dI_{a2}}{dt} = \frac{R_g \frac{di_1}{dt} g_{m2} - \frac{R_L}{r_{p2}} \cdot \frac{di_2}{dt}}{1 + \frac{R_L}{r_{p2}}} \quad \dots \quad \dots \quad (16)$$

yielding finally the circuit equations:

$$\left(R_L + R_g - \frac{R_L^2/r_{p1}}{1 + R_L/r_{p1}} \right) \frac{di_1}{dt} + \frac{1}{C_c} i_2 + \left(R_L + R_g - \frac{R_L^2/r_{p2}}{1 + R_L/r_{p2}} \right) i_2 = 0 \quad \dots \quad (17)$$

From the above, by algebraic reduction the following equation is obtained:

$$\begin{aligned} \frac{di_1}{dt} &= \frac{\left(R_L + R_g - \frac{R_L^2/r_{p2}}{1 + R_L/r_{p2}} \right) \frac{i_1}{C_c} - \frac{R_L R_g g_{m1} i_2}{1 + R_L/r_{p1}} \cdot \frac{1}{C_c}}{\frac{R_L^2 R_g^2 g_{m1} g_{m2}}{(1 + R_L/r_{p1})(1 + R_L/r_{p2})} - \left(R_L + R_g - \frac{R_L^2/r_{p1}}{1 + R_L/r_{p1}} \right) \cdot \left(R_L + R_g - \frac{R_L^2/r_{p2}}{1 + R_L/r_{p2}} \right)} \\ &\equiv \frac{P}{R} \quad \dots \quad (18) \end{aligned}$$

Note.—Equations (17) and (18) have their counterparts in terms of di_2/dt .

From equation (18) and its counterpart, the equation for the trajectories in the plane of i_1 and i_2 is found,

$$\frac{di_1}{di_2} = \frac{P}{Q} \quad \dots \quad \dots \quad \dots \quad (19)$$

The methods of nonlinear mechanics can be applied to this equation with the results mentioned below:

(1) The point $i_1 = i_2 = 0$ is a singular point because the function di_1/di_2 becomes indeterminate at this point.

(2) The nature of this singularity may be investigated by noticing that

$$\left(R_L + R_g - \frac{R_L^2/r_p}{1 + R_L/r_p} \right)$$

is always positive, and that near $i_1 = i_2 = 0$, the expression $(g_{m1}/(1 + R_L/r_{p1}))$ may be replaced by a constant k_1 , and $(g_{m2}/(1 + R_L/r_{p2}))$ by another constant k_2 , thus making it possible to write:

$$\frac{di_1}{dt} = \left(R_L + R_g - \frac{R_L^2/r_{p2}}{1 + R_L/r_{p2}} \right) \frac{i_1}{M} - \frac{R_L R_g k_1}{M} i_2 \quad \dots \quad \dots \quad (20)$$

and

$$\frac{di_2}{dt} = \left(R_L + R_g - \frac{R_L^2/r_{p1}}{1 + R_L/r_{p1}} \right) \frac{i_2}{M} - \frac{R_L R_g k_2}{M} i_1 \quad \dots \quad \dots \quad (21)$$

where

$$M = C_c \left[R_L^2 R_g^2 k_1 k_2 - \left(R_L + R_g - \frac{R_L^2/r_{p1}}{1 + R_L/r_{p1}} \right) \left(R_L + R_g - \frac{R_L^2/r_{p2}}{1 + R_L/r_{p2}} \right) \right] \neq 0.$$

The characteristic equation of this system then becomes

$$\lambda^2 - \left(2R_L + 2R_g - \frac{R_L^2/r_{p1}}{1 + R_L/r_{p1}} - \frac{R_L^2/r_{p2}}{1 + R_L/r_{p2}} \right) \frac{\lambda}{M} - \frac{1}{C_c M} = 0 \quad \dots (22)$$

The nature of the roots of this equation obviously depends on the sign of M . When M is negative, the origin is a stable point, and hence this condition is not of interest for relaxation oscillations. When M is positive, then both the roots of (22) are real and bear opposite signs, signifying that the point $i_1 = i_2 = 0$ is unstable. It is further to be noted that as i_1 and i_2 increase (one positively and the other negatively) the factor k involved in the expression for M , changes. This change will make one of the k 's decrease to zero, making M negative and allowing the circuit to relax.

(3) According to the theorem of I. Bendixson the system can possess no closed analytic trajectories if the expression

$$\frac{\partial P}{\partial i_1} + \frac{\partial Q}{\partial i_2},$$

referring to the differential equation (18) and its counterpart does not change sign in a certain domain of i_1 and i_2 . The sum of the two partial derivatives in the present case will be

$$\left(2R_L + 2R_g - \frac{R_L^2/r_{p1}}{1 + R_L/r_{p1}} - \frac{R_L^2/r_{p2}}{1 + R_L/r_{p2}} \right) / C_c$$

which is permanently positive. No closed trajectories are, therefore, possible.

(4) The equation for the critical points is the following:—

$$R_L^2 R_g^2 k_1 k_2 - \left(R_L + R_g - \frac{R_L^2/r_{p1}}{1 + R_L/r_{p1}} \right) \left(R_L + R_g - \frac{R_L^2/r_{p2}}{1 + R_L/r_{p2}} \right) = 0 \quad \dots (23)$$

This is roughly sketched in Fig. 3, and as explained before the trajectories given by (19) will approach this locus of the critical points. When the representative point

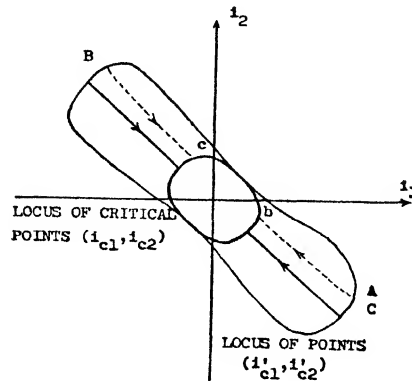


Fig. 3. Locus of Critical points.

moving along a trajectory will reach this locus, it will be shifted instantaneously to some other point from where a new trajectory will be followed. Thus to each point (i_{1c}, i_{2c}) on the locus of the critical points there will be a corresponding point (i'_{1c}, i'_{2c}) such that a new trajectory will start from the latter point. By application of the Mandelstam conditions on the voltage across the condensers, that is by equating voltages at (i_{1c}, i_{2c}) and (i'_{1c}, i'_{2c}) , the form of the locus of the points from which the trajectories start can be found. This is also shown in Fig. 3. A trajectory starting at the point A will reach b which is a critical point; a jump bB will then take place with a new trajectory Bc starting from B . From c the representative point will jump to C and a new trajectory will start from there. Ultimately the system will reach a steady state trajectory shown in full lines in Fig. 3.

Discussion of the Discontinuous Theory.

This theory is very effective as long as the assumptions made closely describe the conditions in a particular system. But like all other theories the reliability of the results obtained with the help of this theory is directly proportional to the reality expressed in the assumptions. In the multivibrator operation the time taken for one tube to switch on and for the other to switch off is really negligible when the repetition rate (or the frequency) is small, there is no appreciable effect caused by the inductance in the circuit, and the treatment outlined above very nearly describes the functioning of the circuit. However, if interest is centered on higher frequencies, the time of switch-over assumes greater importance relative to the period between two switch-overs, and the Discontinuous Theory, by its very nature has no information to give on this phenomenon.

At higher frequencies the shunting and interelectrode capacitances, as is well known, become quite important, and when they have to be taken into account the Bendixson criterion, which is only a negative criterion, breaks down. It is evident, therefore, that when the shunting capacitance C is present even the information previously given by the discontinuous treatment (not to say of the information precluded by the method) becomes seriously limited. If the above fact is taken in conjunction with the possibility of the presence of other parasitic inductances and capacitances, it becomes quite evident that the Discontinuous Theory, in spite of its mathematical soundness, becomes a rather complicated tool at the higher frequencies so common in present physics and engineering practice.

In spite of the many developments in the nonlinear method it appears that in order to study circuit behaviour at high frequencies so as to have some quantitative information on transient and fast phenomena, one has to look for some other means of analysis. In doing this some approximations are bound to be made but as long as the task of analysing the circuit is simplified without spoiling the validity of the results for practical application, such approximations can be acceptable. For example, if the operational range of the currents and voltages in the tube is very small it is quite possible to approximate the nonlinear characteristic by a straight line within that range. This limitation simplifies the analysis considerably and makes it possible to write circuit equations in a linear form which then can be solved by well-known methods.

REFERENCES.

- Abraham, H. and Bloch, E. (1927). Mesure en valeur absolue des periodes oscillations electriques de haute frequence. *Ann. de Phys.*, **12**, 114-118.
 Benjamin, R. (1940). Blocking Oscillator. *Jour. I.E.E. (London)*, **93**, 1159-1175.
 Brainard, J. G. and Weygandt, C. N. (1936). Unsymmetrical Self-Excited Oscillations in Certain Simple Nonlinear Systems. *Proc. I.R.E.*, **24**, 914-922.
 Kryloff, N. and Bogoliuboff, N. (1943). Introduction to Nonlinear Mechanics. A free translation by Solomon Lefschetz of excerpts from two Russian monographs. Princeton Univ. Press; also Oxford Univ. Press.

- le Corbeiller, Ph. (1936). A Nonlinear Theory of the Maintenance of Oscillations. *Jour. I.E.E. (London)*, Part III, **79**, 361-378.
- Levinson, N. and Smith, O. K. (1942). A General Equation for Relaxation Oscillations. *Duke Math. Jour.*, **9**, 382-405.
- Ludeke, C. A. (1949). A Method of Equivalent Linearization for Nonlinear Oscillatory Systems with large Nonlinearity. *Jour. of App. Phys.*, **20**, 694-699.
- Mandelstam, L. and Papalexi, R. (1935). Expose des recherches recentes sur les oscillations nonlinears. *Jour. of Tech. Phys. of the U.S.S.R.*, II, No. 2-3, 81-134.
- Minorski, N. (1947). Introduction to Nonlinear Mechanics. J. W. Edwards, Ann Arbor.
- Shohat, J. A. (1944). On van der Pol's and Related Nonlinear Differential Equations. *Jour. of App. Phys.*, **15**, 568-574.
- Teodorichik, K. (1945). A Nonlinear Theory of R-C Generators. *Jour. of Phys., U.S.S.R.*, **9**, 341-345.
- (1945). Nyquist Diagrams for a Thomson System with Two Degrees of Freedom and Their Interpretation. *C.R. de l'Academie des Sciences de l'U.R.S.S.*, **49**, 259-262.
- (1946). On the Theory of Sinusoidal Auto-Oscillations in Systems with Many Degrees of Freedom. *Ibid.*, **52**, 33-36.
- von Karman (1940). The Engineer Grapples with Nonlinear Problems. *Bull. Am. Math. Soc.*, **46**, 615-684.

CONSTRUCTION OF A NEW COMBINED VACUUM FURNACE AND MASS SPECTROMETER FOR UNIVERSAL USE.

By B. N. SRIVASTAVA, *D.Sc., F.N.I.,** and V. N. SAHARIA, *M.Sc., Department of Physics, University of Allahabad.*

(Received February 22 ; read March 3, 1950.)

1. INTRODUCTION.

The vacuum graphite furnace constructed by Saha and Tandon (1936) has been used till now in studying the Lattice energies of alkali halides and electron affinities of halogens (Saha and Tandon 1937, Tandon 1937*a*, 1937*b*, Srivastava 1938, 1939), the thermal ionisation of Ba, Sr, (Srivastava 1940*a*, 1949*b*) Na and K (Bhatnagar 1943), Li (Srivastava and Bhatnagar 1946), Ca and Al (Bhatnagar 1947*a*, 1947*b*). The thermionic work function of graphite (Bhatnagar 1944), molybdenum and iron (Mathur†) and the effect of space charge on electronic currents (Srivastava and Bhatnagar 1944) have also been studied with the help of the furnace.

The method consisted essentially in vaporizing the substance in an auxiliary furnace and then bringing the vapour to an electrically heated graphite furnace of much higher temperature where the molecules suffer thermal dissociation into atoms and ions. The products of dissociation effuse out through an orifice and are collected by a Faraday cylinder, the current being measured by a sensitive galvanometer. The currents due to positive and negative ions are separately measured by applying a suitable negative or positive accelerating potential to the Faraday cylinder.

The first attempt to distinguish between the current due to negative ions and electrons was made by Srivastava (1938) by inserting an electromagnet in such a position that the magnetic field was perpendicular to the effusing ion beam. On applying the magnetic field the electrons were completely deflected off and the negative ion current alone could be measured.

The method was successful in eliminating only the electrons from the ion beam because the mass of the electrons is about 2,000 times less. There may be present in the beam many types of ions of like charge but not differing so much in mass, as is the case with the ions of various elements, and these could not be separated by this method. Further the masses of the ions could not be determined. A method was later developed from the space charge theory by Srivastava and Bhatnagar (1944*a*, 1944*b*) and Srivastava (1946), for finding the masses of these ions in case of unipolar unicomponent beams, but this is not applicable to a bipolar or bicomponent mixture (Srivastava and Bhatnagar 1946). Further multiply charged ions would create a difficulty of their own. It is clear therefore that for an accurate quantitative analysis of the different types of ions in the effusing beam we require some sort of mass spectrometer arrangement which should collect all particles of the same mass at one place, so that these can be measured separately from others.

With this end in view the apparatus described in this paper has been designed.

2. PRINCIPLES OF MASS SPECTROGRAPH DESIGN.

Since the time of Aston's first mass spectrograph various types of mass spectrographs and spectrometers have been designed with a view to obtain high dispersion,

* Now in Lucknow University.

† Not yet published.

high resolution and sharp focussing. In the earlier mass spectrographs the beam of mass rays was made homogeneous in some respect before the focussing device was applied. In Dempster's first apparatus (1918) an ion beam of constant energy was deflected and focussed geometrically in a uniform magnetic field. In the Bainbridge spectrograph (1930) and that of Smythe and Mattauch (1926, 1932) a particular velocity is selected by a velocity selector and then deflected and focussed geometrically in the first case by a uniform magnetic field and in the second by a radial electric field.

In all the foregoing apparatus a very sharp focus could not be obtained unless the incident beam was carefully collimated to a perfect linear beam. In actual experiments, however, the beam is somewhat divergent and therefore for a proper design of modern high power mass spectrograph it was essential to investigate the conditions of double focussing. This was completely worked out theoretically by Hertzog, and Mattauch and Hertzog (1934) for all arrangements of a radial electric field and a homogeneous magnetic field for producing both direction and velocity focussing. The double focussing mass spectrographs of Bainbridge and Jordon (1936), of Mattauch (1936) and of Jordon (1940) were constructed fully satisfying the foregoing conditions of double focussing. The double focussing mass spectrograph of Dempster (1935), however, does not fully satisfy these conditions of double focussing. The incident beam employed in all these spectrographs is either of constant energy or of constant velocity.

3. MASS SPECTROMETERS ALREADY USED FOR INVESTIGATING IONS.

Several investigators such as Smith (1925), Lawrence (1926), Barton (1927), Hamwell (1927), Hogness and Harkness (1928) have used mass spectrometer of the 180° magnetic focussing type for investigating ions of such substances which exist in the gaseous state or are easily volatilized. The substances studied were hydrogen, iodine, HCl, and the rare gases, and ions were produced by bombarding molecules of these substances by accelerated electrons obtained from heated filaments. The method suffers from several limitations. Firstly, it is very difficult to isolate ions of uniform velocity from the collision space as they will be produced at different places in the chamber and are mixed with electrons. Secondly, only gases and vapours could be studied by this method. Thirdly, the method can only indicate the existence of the various types of ions; the so-called relative abundances observed are of no use in giving us any further information about the quantitative aspects of the reactions involved since the transition probabilities, the precise conditions of reaction, etc., are not fully known or determinable.

We have therefore tried to devise a mass spectrometer which should be capable of studying ions of all substances and be therefore of universal applicability. Further we produce the ions under conditions fully amenable to theoretical treatment. In practice the ions were produced under conditions of perfect thermodynamical equilibrium by heating the vapour inside a graphite furnace under black body conditions.

4. THEORY OF THE MAGNETIC REFOCUSING USED IN OUR MASS SPECTROMETER.

The refocussing property of magnetic fields has been discussed by W. E. Stephens (1934). A particular case of this is the 60° magnetic focussing used in our mass spectrometer.

Suppose a uniform magnetic field of intensity H in a direction perpendicular to the paper, is limited by boundaries OPQ and OWV (Fig. 1), which make angles θ and γ respectively with the normal to the line AO . Inside the region $QPOWV$ the electron paths will be arcs of circle.

Suppose a homogeneous beam of particles of velocity v enters through a slit A and falls perpendicularly on OPQ at P . If the intensity H of the magnetic field is

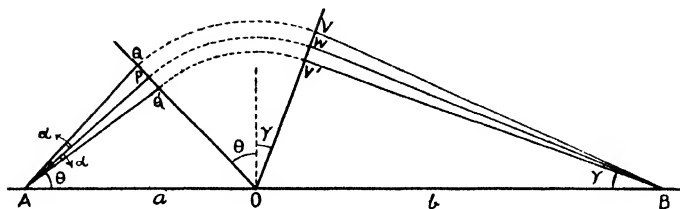


FIG. 1.

such that it bends the beam in an arc of a circle whose radius of curvature $R = a \sin \theta = OP = OW$, then the centre of curvature of the arc will be O and the beam leaves at W perpendicular to OW meeting the line AO produced at B . The required intensity of the field is given by $H = Re/mvc$. Slightly divergent beams such as AQV and $AQ'V'$ having the same velocity v but making angle $\pm \alpha$ with AP will cross very close to B . It is clear that best refocussing is obtained at a point B such that

$$OB = b = \frac{a \sin \theta}{\sin \gamma}.$$

The spreading S and dispersion D at B are given by

$$S = \frac{a\alpha^2}{2} \left[\frac{\sin^2 \theta}{\sin \gamma} + \frac{\sin^2 \gamma}{\sin \theta} \right],$$

$$D = a \frac{\sin \theta}{\sin \gamma} \frac{\Delta v}{v} (\sin \theta + \sin \gamma).$$

When $\theta = \gamma$,

$$S = a\alpha^2 \sin \theta,$$

$$D = 2a \sin \theta \frac{\Delta v}{v},$$

and

$$a = b.$$

Considering the space available to us inside the evacuated space and certain other limitations we decided to construct a Dempster type of mass spectrometer in which ions of constant energy are incident. Instead of double focussing, a simple 60° magnetic refocussing as used by Nier (1940) has been employed. We have found $\theta = 30^\circ$ and $a = b = 3$ cm. as convenient for our design. The radius of curvature $R = 1.73$ cm. The geometry of the focussing is illustrated in Fig. 2.

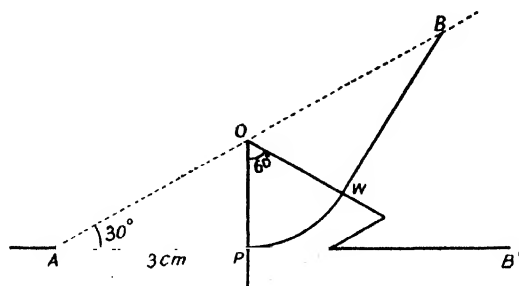


FIG. 2.

$$\begin{aligned} \theta &= \gamma = 30^\circ \\ a &= b = 3 \text{ cm.} \\ R &= 1.73 \text{ cm.} \end{aligned}$$

The general arrangement of the assembly is shown in Fig. 3. The positions of the graphite tube G , slit C , magnetic field M and Faraday cylinder F_1 , F_2 are indicated in the figure.

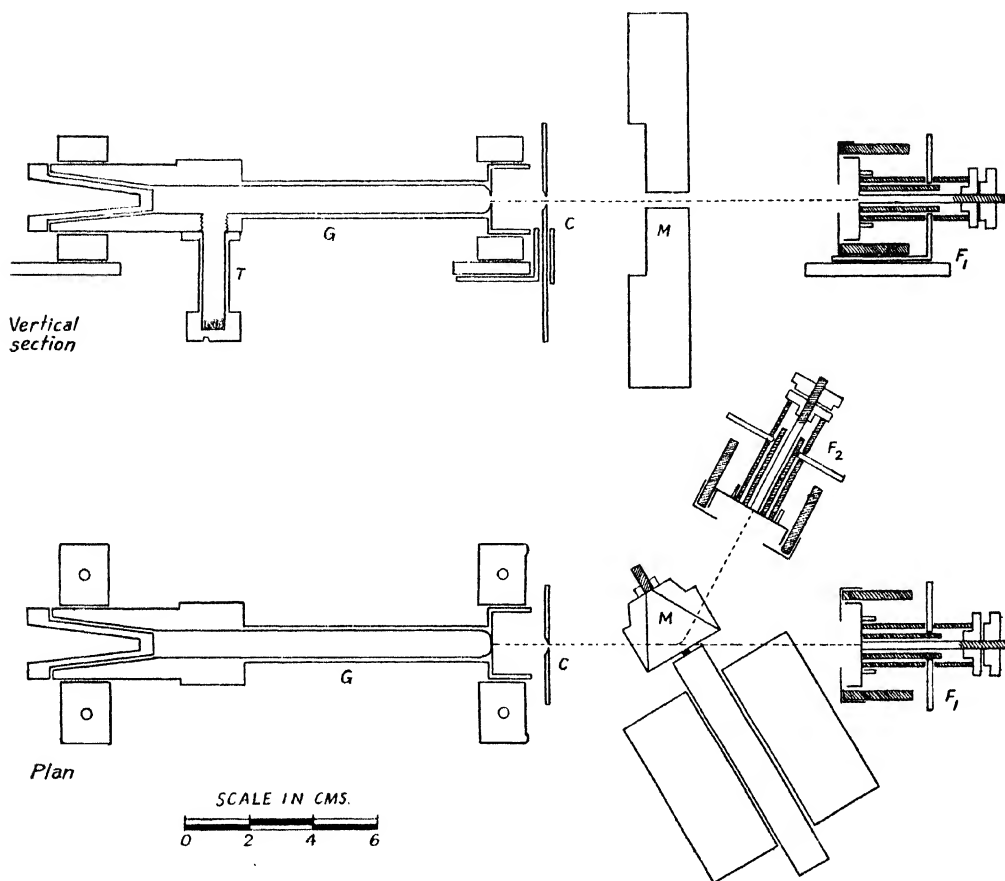


FIG. 3.

5. DESIGN OF THE MASS SPECTROMETER.

The apparatus consists of four parts:—

- (i) Ion source.
- (ii) Accelerating slit.
- (iii) Magnetic field.
- (iv) Collector.

(i) *Ion Source*.—This is a graphite tube G which is heated by passing a current of about a thousand amperes from a low tension transformer. The graphite tube is mounted on copper electrodes which carry the heating current and which are themselves attached to water-cooled brass tubes leading outside the evacuated chamber through electrically insulated and vacuum-tight junctions for the purpose of electrical connection. The experimental details of this arrangement, as well

as the enclosing drum and the connections to the pumps were exactly the same as described by Saha and Tandon (1936). This graphite tube, which we call the main furnace, has a side-tube *T* of graphite or iron attached to it, which was heated by thermal conduction as in the experiments of Srivastava (1940). This side-furnace contained the substance under investigation in the solid or liquid state and the vapour of this substance on entering the main furnace suffers thermal dissociation into atoms, ions and electrons. The products of dissociation effuse out of a narrow orifice of diameter 2.0 mm. producing a composite ion beam consisting of particles of all velocities obeying Maxwell's distribution law.

(ii) *Accelerating slit*.—For producing ions of constant energy out of this non-homogeneous beam it is necessary to accelerate these ions by applying a high potential. Since the thermal velocities are of the order of 0.5 volt, an accelerating voltage of about 30 volts is sufficient to produce a homogeneous beam. This voltage is applied to the slit *C* with respect to the graphite tube which is earthed. The slit *C*, which also acts as the defining slit, has to be properly mounted, aligned and insulated. The method of support is illustrated in Fig. 4. The L-shaped iron plate *P* is fixed to the slotted copper plate supporting the graphite blocks. To the vertical arm of *P* is attached another iron plate *Q* which is tightened by two screws *x* and *y*, and another iron plate *R* containing the defining slit (which is in the form of a circular hole of 3.0 mm. diameter), is supported in between these two plates, but is

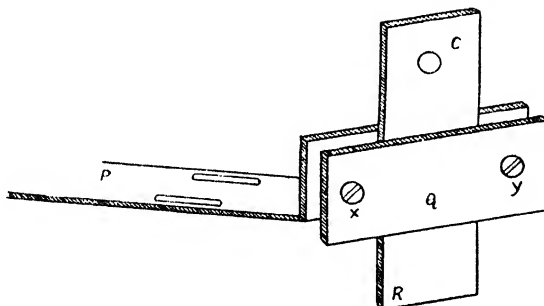


FIG. 4.

carefully insulated from the latter by mica sheets on either side of it. Suitable arrangements are provided for adjusting the distance from the ion source, the height and alignment of the slit.

(iii) *Magnetic field*.—The design and construction of a suitable electromagnet is a major problem in these investigations. For success in these experiments it is essential that the magnetic core should be of such ferromagnetic material which possesses high permeability and low retentivity (small hysteresis loop). The only material available to us satisfying these criteria were transformer stampings. A large number of such U-shaped stampings were rivetted together and two light brass spools, each having 1,000 turns of No. 21 S.W.G. enamel wire, were mounted on either arm of the stamping. The ends of each winding were brought out separately so that the two spools may be connected either in series or in parallels. Mica has been used after every second layer of winding to further improve the insulation.

As already explained the pole-pieces should be so designed as to produce a homogeneous, wedge-shaped magnetic field, the angle between the faces of the wedge being 60° . Further the fringing effect of the magnetic field had to be taken into account to determine the actual extent of the magnetic field in order to locate

correctly the position of the collector. Pole-pieces were made out of an electromagnetic specimen of soft iron and were in the form of a trapezoid of 5.3 cm. in thickness, the four sides measuring 2.5, 2.3, 0.5, 2.3 cm. respectively. Slots in the pole-pieces made it possible to vary the air gap from 0.5 cm. to 1.5 cm. The two cross-sectional views of the electromagnet are shown in Fig. 5.

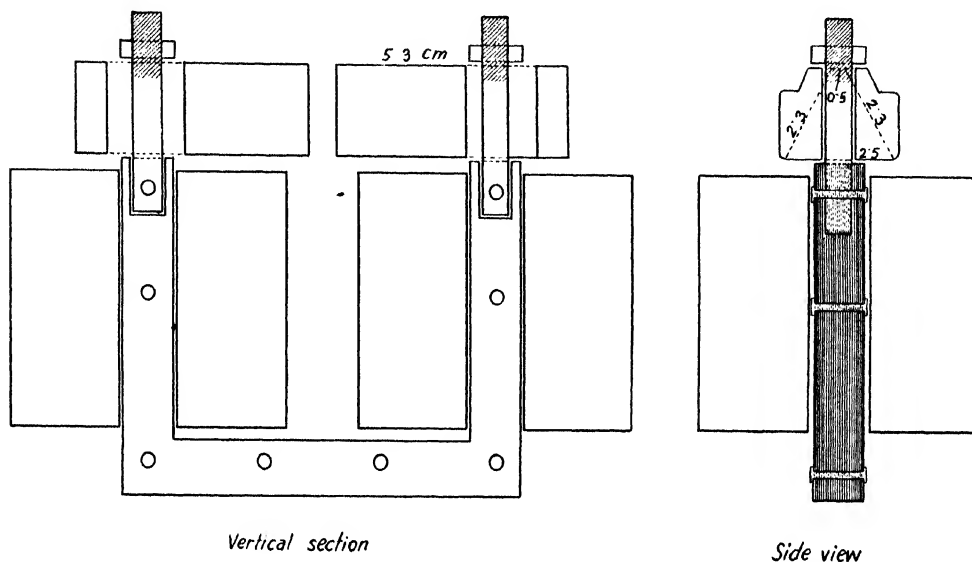


FIG. 5.

The mounting of the electromagnet is shown in Fig. 6. An iron rod *A* has been clamped to one of the electrodes *E* by means of a clamp *C*. The iron rod is insulated from the electrode by placing mica between the clip and electrode. To

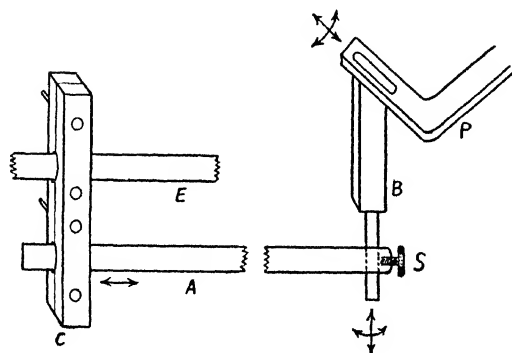


FIG. 6.

this rod is fixed by means of a screw *S* a vertical brass support *B* which carries at its other end a screw and slot arrangement for attaching to it a curved brass strip *P*. The other end of this strip is fixed to the arm of the electromagnet.

The whole arrangement is quite rigid and possesses the advantage of allowing all possible adjustments of electromagnet. The various possible adjustments are indicated by the arrows.

(iv) *Collector*.—There are two Faraday cylinders F_1 , F_2 , (Fig. 3) to collect the beam of ions, one for the direct, and the other for the deflected beam. They are made of brass and mounted on a L-shaped iron plate L (Fig. 7), but insulated from the latter by means of quartz tubes. The iron plate itself is clamped to a horizontal copper plate fixed to one of the brass electrodes. The iron plate carrying the Faraday cylinder and the supporting copper plate, both are slotted but in perpendicular directions, and hence the Faraday cylinder can be adjusted and

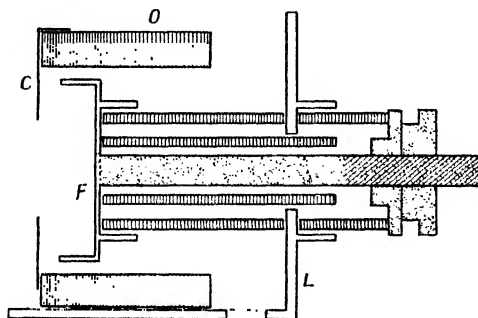


Fig. 7.

fixed in any desired position and direction. For preventing stray ions from reaching the Faraday cylinder, a small wide quartz tube O is mounted over the latter, and a cap C made of brass with a hole in the centre is fitted on this quartz tube.

Seven connecting leads have been brought out of the evacuated chamber as follows: Two for the two Faraday cylinders, two for the electromagnet, two for the thermo-couple (which is Pt, Pt-Rh couple) for measuring the temperature of the side-furnace, and one for the potential on the accelerating slit. The slit and the two caps of the Faraday cylinder were connected together so that the ions may travel in field-free space. The temperature of the main furnace is measured by a Leeds and Northrup's disappearing filament pyrometer.

The whole chamber is evacuated by means of two four-stage mercury diffusion pumps in parallel with a speedy-vac backing pump and is properly cooled by a water jacket. Pressure up to 10^{-4} mm. of mercury can be reached within an hour of starting the pumps.

The adjustment and working of the apparatus will be described in a later paper along with the results obtained.

We record with pleasure our thanks to the Government of the United Provinces for the award of a research grant of Rs.2,300 annually which enabled the award of a research scholarship to one of us (V.N.S.).

SUMMARY.

In this paper, the design and construction of a new combined vacuum graphite furnace and mass spectrometer has been fully described and its advantages over other mass spectrometers discussed. It is very convenient to handle and is of universal applicability since it can be used to produce with ease ions of all substances and of all types under black-body conditions and all these ions can be separately collected and measured. The apparatus is likely to prove of great utility in a variety of measurements with negative and positive ions.

REFERENCES.

- Bainbridge and Jordon (1936). Mass Spectrum analysis. *Phys. Rev.*, **50**, 282.
- Barton, H. A. (1927). The ionisation of HCl by electron impacts. *Phys. Rev.*, **30**, 614.
- Bhatnagar, A. S. (1943). Thermal ionisation of sodium and potassium atoms. *Proc. Nat. Acad. Sci. Ind.*, **13**, 243.
- (1944). The thermionic work function of graphite. *Proc. Nat. Acad. Sci. Ind.*, **14**, 5.
- (1947a). Thermal ionisation of calcium. *Proc. Nat. Acad. Sci. Ind.*, **16**, 45.
- (1947b). Thermal ionisation of aluminium. *Proc. Nat. Acad. Sci. Ind.*, **16**, 53.
- Denipster, A. J. (1918). A new method of positive ray analysis. *Phys. Rev.*, **11**, 316.
- (1935). New methods in mass spectroscopy. *Proc. Amer. Phil. Soc.*, **75**, 755.
- Hamwell, G. P. (1927). Ionisation by collisions in rare gases. *Phys. Rev.*, **29**, 683.
- Hogness, T. R. and Harkness, R. W. (1928). Ionisation processes of iodine interpreted by mass-spectrograph. *Phys. Rev.*, **32**, 784.
- Jordon (1940). A new mass spectrograph, etc. *Phys. Rev.*, **57**, 1072.
- Lawrence, E. O. (1926). Ionisation of atoms by electron impact. *Phys. Rev.*, **28**, 947.
- Mattauch, J. (1936). A double-focussing mass spectrograph. *Phys. Rev.*, **50**, 617.
- (1932). Über neue Methoden der Massenspektrometrie. *Phys. Zeits.*, **33**, 899.
- Mattauch, J. and Hertzog, R. (1934). Über einen neuen Massenspektrographen. *Zeits. Phys.*, **89**, 786.
- Nier, A. O. (1940). Mass spectrometer for isotope abundance measurements. *Rev. Sci. Inst.*, **11**, 212.
- Saha, M. N. and Tandon, A. N. (1936). A new demountable vacuum graphite furnace. *Proc. Nat. Acad. Sci. Ind.*, **6**, 212.
- (1937). Experimental determination of the electron affinity of chlorine. *Proc. Nat. Inst. Sci. Ind.*, **3**, 287.
- Smith, H. D. (1925). Primary and secondary products of ionisation in hydrogen. *Phys. Rev.*, **25**, 452.
- Smyth, R. W. (1926). A velocity filter for electrons and ions. *Phys. Rev.*, **28**, 1275.
- Srivastava, B. N. (1938). Heat of dissociation of iodides of Rb and Li, etc. *Proc. Nat. Inst. Sci. Ind.*, **4**, 365.
- (1939). Heat of ionic dissociation of RbCl and RbBr. *Proc. Nat. Inst. Sci. Ind.*, **5**, 313.
- (1940a). Thermal ionisation of barium. *Proc. Roy. Soc. Lond.*, **175**, 26.
- (1940b). Thermal ionisation of strontium. *Proc. Roy. Soc. Lond.*, **176**, 343.
- (1946). Effect of space charge on electronic currents. Part III. *Proc. Nat. Acad. Sci. Ind.*, **15**, 165.
- Srivastava, B. N. and Bhatnagar, A. S. (1944a, b). Effect of space charge on electronic currents, Part I—Theoretical, Part II—Experimental. *Proc. Nat. Acad. Sci. Ind.*, **14**, 106.
- (1946). Thermal ionisation of lithium and specific charge of Li⁺. *Proc. Nat. Acad. Sci. Ind.*, **15**, 175.
- Stephens, W. E. (1934). Magnetic refocussing of electron paths. *Phys. Rev.*, **45**, 513.
- Tandon, A. N. (1937a). Lattice energy of KBr and NaBr, etc. *Ind. Jour. Phys.*, **11**, 99.
- (1937b). Lattice energy of KI and NaI, etc. *Proc. Nat. Acad. Sci. Ind.*, **7**, 102.

ADAPTIVE MODIFICATIONS IN A HILL-STREAM CATFISH,
GLYPTOTHORAX TELCHITTA (HAMILTON).

By BIMLA BHATIA, M.Sc., Zoological Laboratories, University of Delhi.

(Communicated by Dr. S. L. Hora, F.N.I.)

(Received February 2 ; read March 3, 1950.)

Since 1920, in a large series of papers, Dr. Hora has thrown considerable light on the ecology, bionomics and evolution of torrential fishes, with special reference to the adaptive modifications undergone by them in response to a rocky substratum and swift currents. Structural modifications of different organs in various types of hill-stream fishes have been dealt with by a number of other workers but, so far as I am aware, no single species of fish has been studied exhaustively. Dr. Hora, therefore, suggested to me the problem of investigating a small catfish, *Glyptothorax telchitta* (Hamilton), and placed some well-preserved material at my disposal for study. During the progress of work I had occasions to discuss my results with Dr. Hora. His knowledge of the habits and habitats of the species has been of great value in understanding the functional morphology of the modifications noticed.

Glyptothorax telchitta was described by Hamilton in 1822, but its precise systematic position has been recently elucidated by Hora and Menon in an article to be published in the *Records of the Indian Museum*. The fish belongs to the order Siluroidea and the family Sisoridae. It is moderately specialized for life in swift currents and is usually found in small, shallow pebbly channels with water flowing at the rate of 6 to 8 feet per second. The general body-form is torpedo-shaped, thus permitting water to flow over it without forming eddies at the posterior end.

The material for this investigation was obtained by Dr. Hora from the Rihand river, near the Pipri Dam Site, in the Mirzapore District, U.P. The fish were fixed in alcoholic Bouin's fluid and, after treatment in 70% alcohol, preserved in rectified spirit. Free hand sections, dissections and 5 to 8 μ thick microtome sections stained with Haematoxylin, Eosin and Iron Haematoxylin were prepared in carrying out these investigations.

I wish to express my deep gratitude to Dr. S. L. Hora for suggesting the problem, giving the material and for watching the progress of work. The work was done under the supervision of Dr. M. L. Bhatia, Zoological Laboratory, University of Delhi, and my sincere thanks are due to him for constant advice and help. I am also thankful to the University authorities for affording me facilities for carrying out these investigations.

It is proposed to deal with the subject in a series of articles, the first dealing with adhesive organs is presented here.

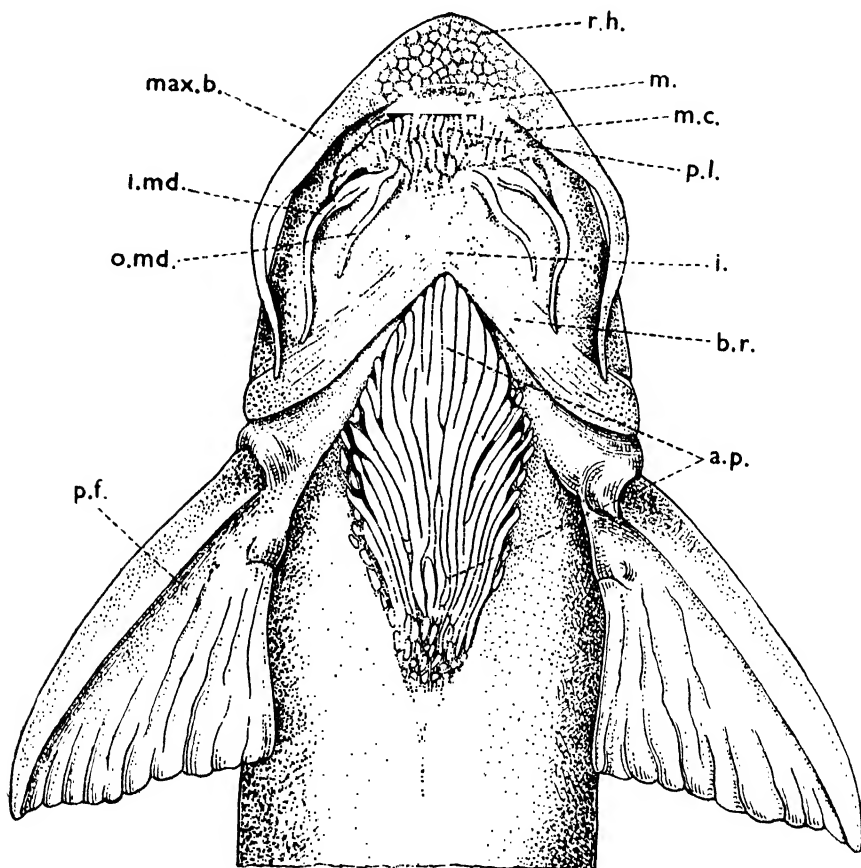
Part I. EPIDERMAL ADHESIVE ORGANS.

Our knowledge of adhesive organs is based chiefly on the work of Hora (1922) who gave an account of these organs in a number of fishes and *inter alia* dealt with those of *Glyptothorax* (= *Glyptosternum*) also. He gave certain histological details but his material was not specially preserved for such studies. Wu and Liu (1940) seemed to have overlooked Hora's work and described the structure of the adhesive organs of a Chinese species of *Glyptothorax*.

A satisfactory account of the structure of adhesive organs is not available in literature, and besides this there are details in the general make up and in the histological structure of the adhesive organ which still need elucidation.

This paper, in addition to giving accurate histological details of the parts modified as adhesive organs, gives also the way different structures are formed, as also the manner in which they function.

The adhesive organs of *G. telchitta* (Text-fig. 1) are associated with the following structures:—



TEXT-FIG. 1.—*Glyptothorax telchitta* (Hamilton). Ventral view of anterior portion of head and body.

a.p., adhesive pad; b.r., branchiostegial region; i., isthmus; i.md., inner mandibular barbel; m., mouth; max.b., maxillary barbel; m.c., mouth channel; o.md., outer mandibular barbel; p.f., pectoral fin; p.l., posterior lip; r.h., rostral hood.

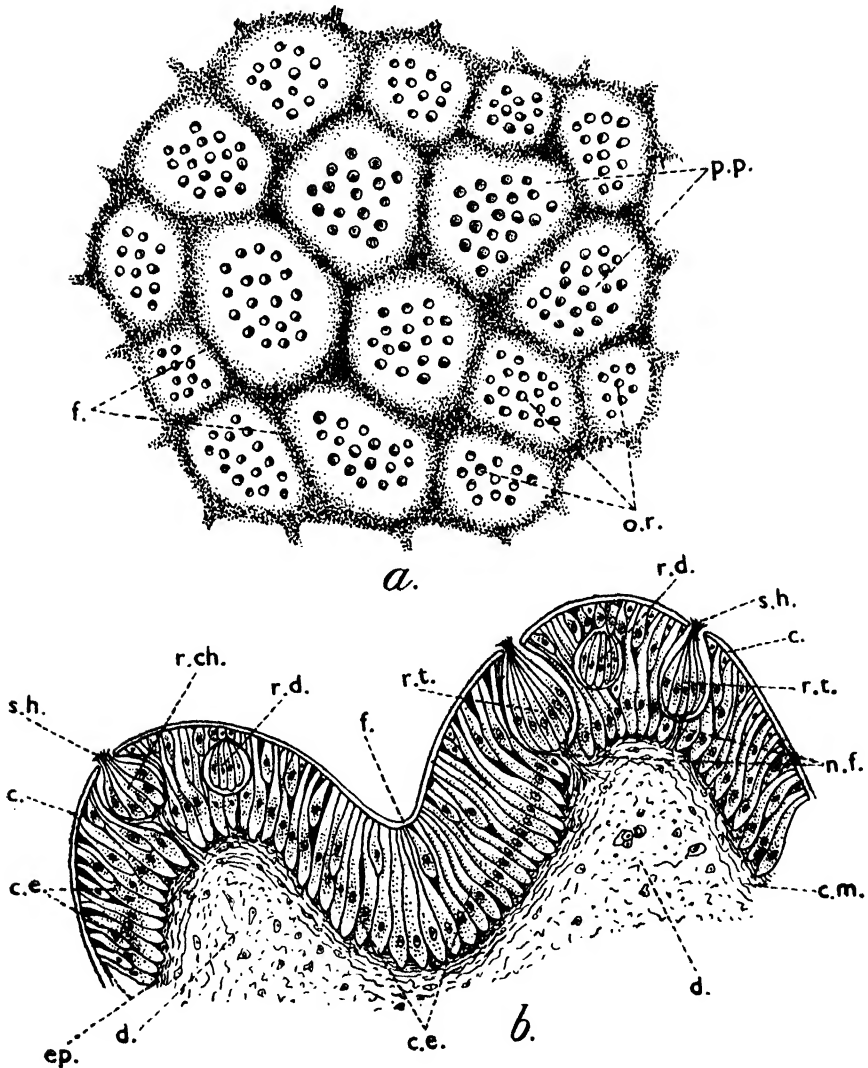
- (i) *The Rostral Hood* (Text-figs. 1, r.h. and 2a, 2b) or the region in front of the mouth and covering the anterior lip.
- (ii) *The Posterior Lip* (Text-figs. 1, p.l., and 3a, 3b) or the region behind the mouth.
- (iii) *The Maxillary barbels* (Text-figs. 1, max.b. and 5).

(iv) *The Region of the Branchiostegial Rays* (Text-figs. 1, *i.* and *b.r.* and 6).

(v) *The Thoracic Adhesive Apparatus* (Text-figs. 1, *a.p.* and 7, 8).

In the following account, the structure of the various regions is considered separately.

(i) *The Rostral hood* (Text-figs. 1 and 2*a*, 2*b*).



TEXT-FIG. 2.—*Glyptothorax telchitta* (Hamilton). Structure of the rostral hood.

a. Flat mount of a small portion of the rostral hood showing polygonal papillae; *b.* Section through rostral hood papillae.

c., cuticle; *c.e.*, columnar epithelial cells; *c.m.*, circular muscle layer; *d.*, dermis; *ep.*, epidermis; *f.*, furrow; *n.f.*, nerve fibre; *o.r.*, openings of receptors; *p.p.*, polygonal papillae; *r.ch.*, chemo-receptor; *r.d.*, developing receptor; *r.t.*, tango-receptor; *s.h.*, sensory hair.

With the shifting of the mouth to the ventral surface, some distance behind the snout, the rostral skin is also carried over to the ventral surface to such an extent as to cover and to mask the anterior lip. This region assumes the appearance of a small pad-like structure in front of the mouth. Under a magnifying lens, the integument here looks profusely papillated and appears to subserve an adhesive function. A lightly stained flat mount of the peeling of this region shows under the microscope a polygonal pattern, (Text-fig. 2a), each polygonal area representing a papilla. On the summit of each papilla is seen a group of 5 to 20 minute circular apertures which, as seen in a section of the papillae, are the external openings of as many receptor organs.

In a section (Text-fig. 2b), each papilla is a more or less conical elevation formed both by the dermis and epidermis. The epidermal layer consists of closely packed spindle-shaped columnar epithelial cells. The entire papilla forms a conical projection on which, as already stated, open 5 to 20 receptors. Text-fig. 2b is of a section passing through two papillae showing three complete and two developing receptors. Each epidermal cell consists of finely granular cytoplasm and has a centrally placed oval nucleus.

A receptor consists of a group of 10 to 15 long slender cells, placed within a flask-shaped cavity. The cytoplasm of the receptor-cells is uniformly granular and a small oval nucleus is placed in the centre of each cell. Each receptor-cell bears fine hair-like processes at its free outer end. The receptors receive their nerve supply at the base, and from their general shape and from the manner of their taking stain, it has been possible to recognize two types of receptors in each group on a papilla, which are presumably Tango-receptors (flask-shaped) and Chemo-receptors (spherical), performing taste and olfactory functions respectively.

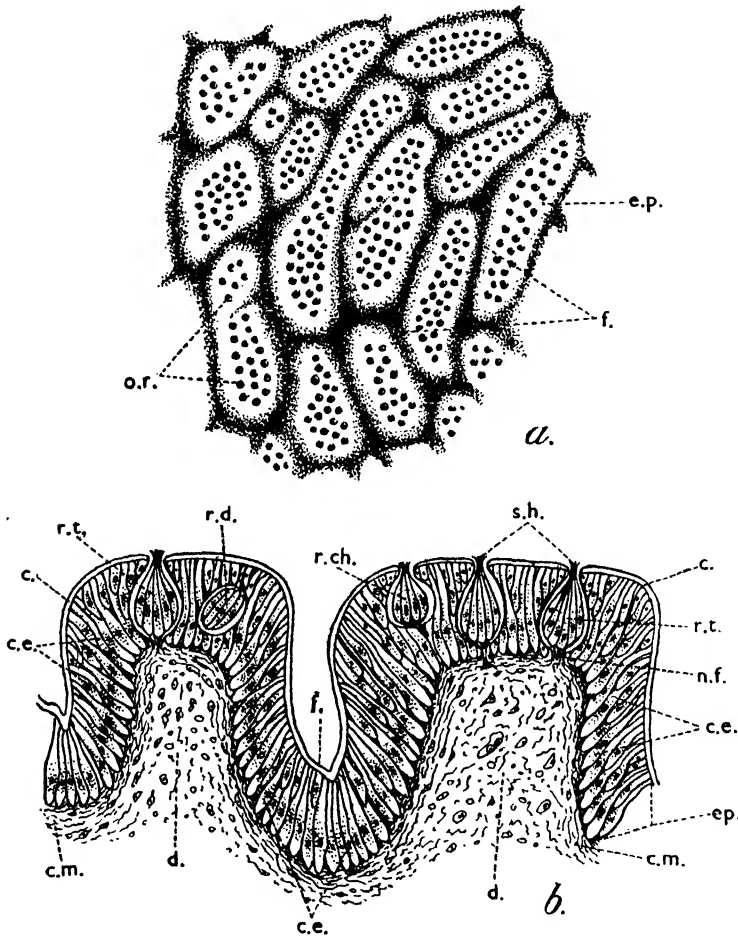
The receptors are modified epidermal cells, and within the series of sections one invariably comes across receptors in the process of formation. In some well stained, properly differentiated sections, it has been possible to see epidermal cells in active state of division, and various developing stages of these receptors. The epidermal cells destined to form receptors, group together, sink deep within the epidermis, and come to lie within a space, before they project out, and start functioning.

(ii) The *Posterior Lip* (Text-figs. 1 and 3a, 3b).

The region immediately behind the mouth may be called the posterior lip. From the position of the mouth, as also of the two lips, it is more appropriate to call these anterior and posterior instead of upper and lower lips. There is a distinctly marked region behind the mouth which is papillated. The epidermis resembles that of the rostral hood and is highly papillated, only the papillae are longish and considerably extensive. They are in the form of long ridges, more well-defined and elevated than those described in the case of the rostral hood. This region appears to be carrying a greater strain than the rostral hood and oblong nature of papillae appears to have secondarily developed as a result of fusion of number of polygonal papillae. In between the long ridges, one notices polygonal papillae of the type seen on the rostral hood, and at some places, 2, 3 or even 4 polygonal papillae combining together to form a long ridge. The summit of each ridge is flat, on which open a large number of receptors, similar to those described in the case of the rostral region. The ridges are well-defined and have steep edges. The histological details of each papilla, and the receptors on these papillae are similar to those found in the rostral region.

The integument behind the posterior lip is not papillated, though it exhibits polygonal pattern, each polygon bearing a group of 4 to 5 receptors. The structures which remained obscure to Ramsay Wright (1884) in the integument of *Amiurus catus*, and which later in *Garra* and *Glyptosternum* (= *Glyptothorax*) were very hesitatingly described by Hora, as gland-cells, are really the receptors. The histological details figured and described by him in *G. labiatum* (Text-fig. 4) are very

similar to those figured here and leave no doubt in my mind about their being receptors even in those forms. After examining the microscopical preparations, Dr. Hora has confirmed my findings and interpretations of these structures as receptors.



TEXT-FIG. 3.—*Glyptothorax telchitta* (Hamilton). Structure of the posterior lip.

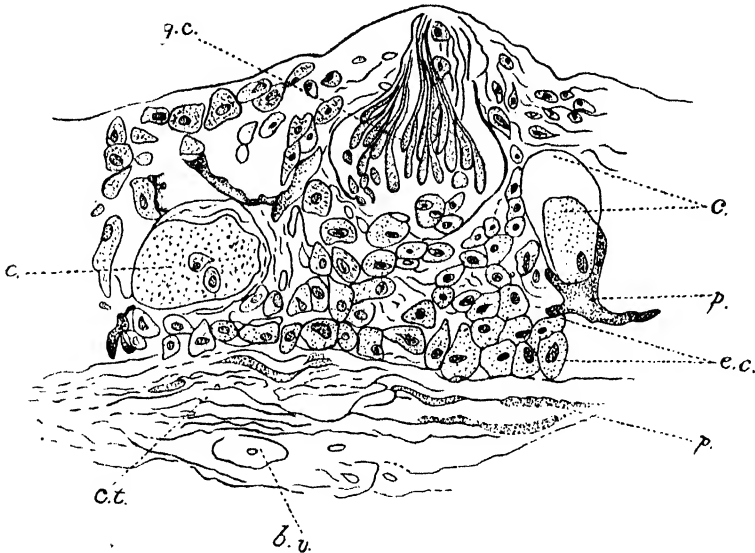
a. Flat mount of small portion of the posterior lip; *b.* Section through the posterior lip papillae.

c., cuticle; *c.e.*, columnar epithelial cells; *c.m.*, circular muscle layer; *d.*, dermis; *ep.*, epidermis; *e.p.*, elongated papillae; *f.*, furrow; *n.f.*, nerve fibre; *o.r.*, openings of the receptors; *r.ch.*, chemo-receptor; *r.d.*, developing receptor; *r.t.*, tango-receptor; *s.h.*, sensory hair.

As to the rostral hood and posterior lip papillae, it may be recalled that in similar papillae on the rostral hood and lower lip of *Garra*, described and figured by Hora (1922, p. 47), the superficial epidermal layer is modified into spines and there are no receptors. Whereas in *Garra* these papillae act as frictional devices, in *Glyptothorax* they seem to function as adhesive organs through adpression. The large number of receptors round the mouth are probably gustatory in function and taste the water flowing into the mouth for respiratory purposes.

(iii) *The Maxillary barbel* (Text-figs. 1 max. b. and 5).

The anterior lip has fleshy backward extensions on the two sides which terminate behind into a pair of cylindrical barbels. Each barbel as seen in a transverse section (Text-fig. 5) has a cartilaginous axial rod which is ensheathed by an inner circular and several bundles of longitudinal layers of muscles, which in turn are surrounded



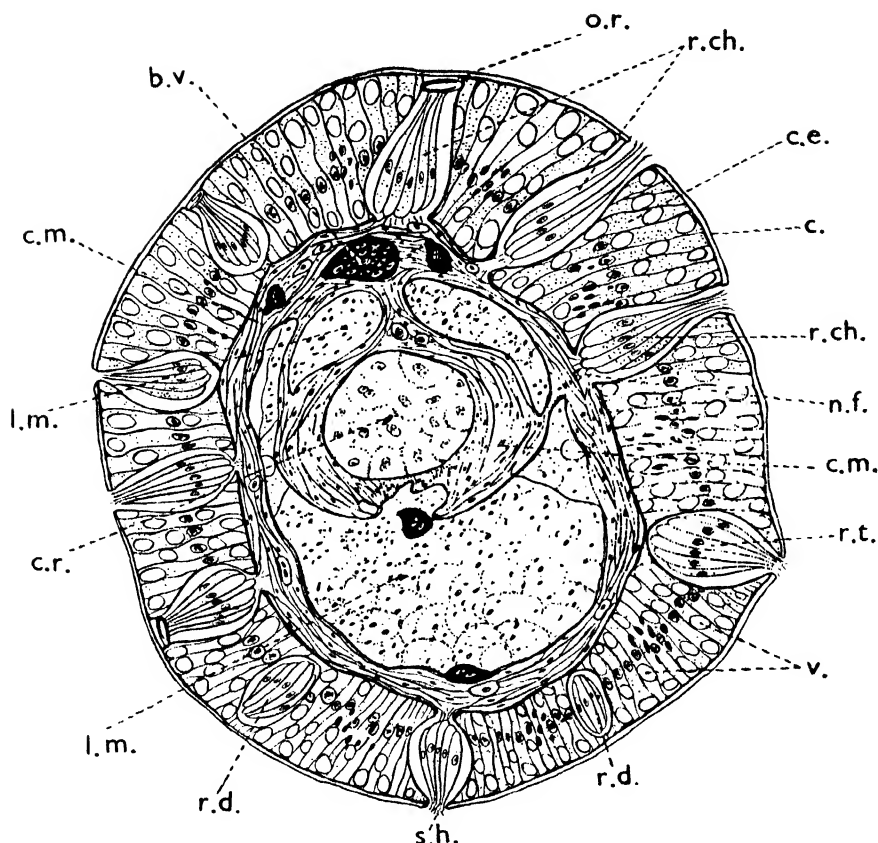
TEXT-FIG. 4.—*Glyptosternum labiatum* (Blyth). Transverse section through the integument. (Reproduction of Hora's Text-figure).

b.v., blood-vessel; c., clavate cell; c.t., connective tissue; e.c., small epithelial cells; g.c., gland cell; p., pigment.

by a second circular layer of muscles. Around this is present a layer of radially arranged epidermal cells which has a thin cuticular covering. The epidermal cells are highly vacuolated, each cell having a finely granular protoplasm and a centrally placed spherical nucleus. In between the epidermal cells there are a large number of receptors which are modified epidermal cells. It is apparent that the barbels are highly sensory and the vacuoles within the epidermal cells add to the turgidity of the barbels to enable them to perform the adhesive function efficiently.

(iv) *The Region of the Branchiostegial Rays* (Text-figs. 1, b.r. and 6a, 6b).

The integument covering the ventral surface of the branchiostegial rays is obliquely fluted, and grooves and ridges run parallel to the branchiostegial rays, and anteriorly meet in the mid-ventral region. A free hand section (Text-fig. 6a) shows the true nature of the integument of this part, as also the nature of the spines on the ridges. The epidermis consists of a well-formed layer of columnar epithelial cells. Each cell has finely granular cytoplasm and an oval nucleus at the base. Next to the epidermal layer, there are several tiers of irregularly scattered cells (the formative cells) which do not form a layer. Both the ridges and the grooves have a cuticular covering which is modified into number of short stout spines over the ridges. The grooves are devoid of spines. A few flask-shaped tango-receptors are also present in this region.



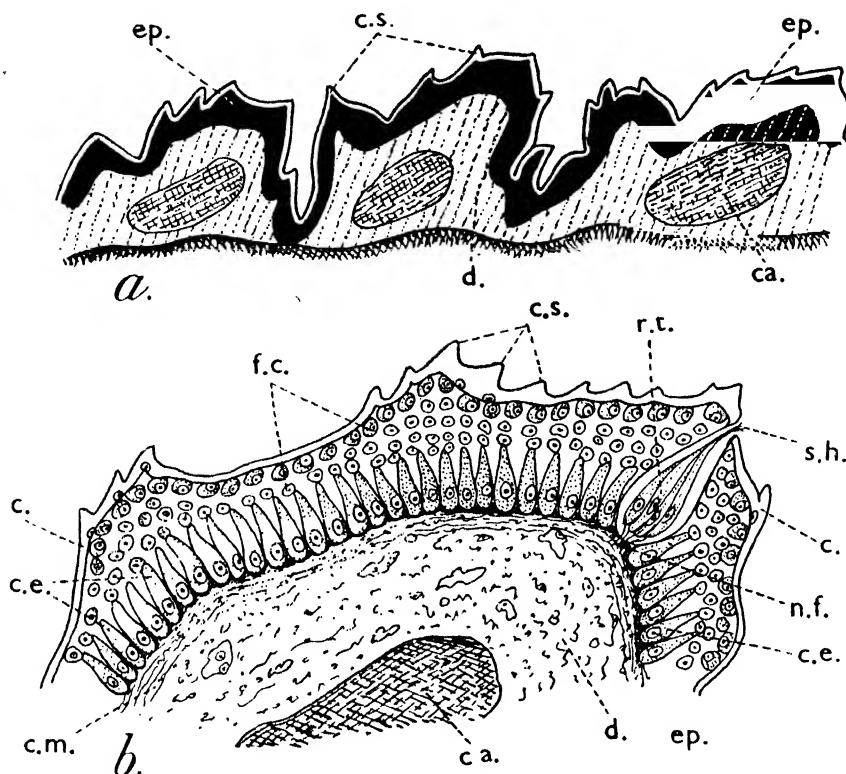
TEXT-FIG. 5.—*Glyptothorax telchitta* (Hamilton). Transverse section through a maxillary barbel. *b.v.*, blood-vessel; *c.*, cuticle; *c.e.*, columnar epithelial cells; *c.m.*, circular muscle layer; *c.r.*, cartilaginous rod; *l.m.*, longitudinal muscle layer; *n.f.*, nerve fibre; *o.r.*, opening of the receptor; *r.ch.*, chemo-receptor; *r.d.*, developing receptor; *r.t.*, tango-receptor; *s.h.*, sensory hair; *v.* vacuoles.

(v) *The Thoracic Adhesive Apparatus* (Text-figs. 1, *a.p.*, 7 and 8).

Like many other hill-stream fishes, the under surface, particularly the ventral thoracic region of this form is flattened so as to come into close contact with the substratum on which the fish rests. The generic name *Glyptothorax* is indicative of this feature of the genus.

The integument of the ventral region, between the bases of the two pectoral fins, has a distinctly marked rhomboidal area which is longitudinally pliated and presents regular corrugations (Text-fig. 1, *a.p.*). A free hand section of a piece of skin from this region (Text-fig. 7) shows longitudinal ridges and alternating grooves. The ridges appear in the form of plates, and are seen bristling with long closely-set spines, the apices of the spines are curved and are all directed backwards. The grooves are without any spines and are smooth.

A microtome section (Text-fig. 8) reveals that while both the dermis and the epidermis form the entire adhesive apparatus (ridges and grooves), it is really the epidermis and its derivatives which are principally concerned with the function of adhesion.



TEXT-FIG. 6.—*Glyptothorax telchitta* (Hamilton). Structure of the branchiostegial region.

a. Free-hand section through the region of the branchiostegial rays; *b.* Microtome section of the same.

ca., cartilage; *c.e.*, columnar epithelial cells; *c.m.*, circular muscle layer; *c.s.*, cuticular spines; *d.*, dermis; *ep.*, epidermis; *f.c.*, formative cells in tiers; *n.f.*, nerve fibre; *r.t.*, tango-receptor; *s.h.*, sensory hair.

The adhesive pad is made up, from inside out, of the following layers:—

- (a) The epidermis,
- (b) Formative cells,
- (c) Beak-shaped cells,
- (d) Cuticle, and cuticular spines.

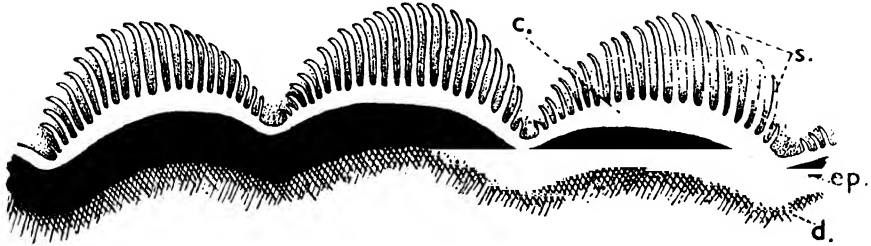
(a) *The epidermis.*

Next to the dermis is the epidermis, a layer of slender, closely packed, columnar epithelial cells. The cytoplasm is uniformly granular and an oval nucleus is placed in the central region of each cell. The cells within this layer are in an active state of mitotic division, and as a result of this division a large number of cells arise from the epidermis which remain scattered towards the outer border of the epidermal layer.

(b) *Formative cells.*

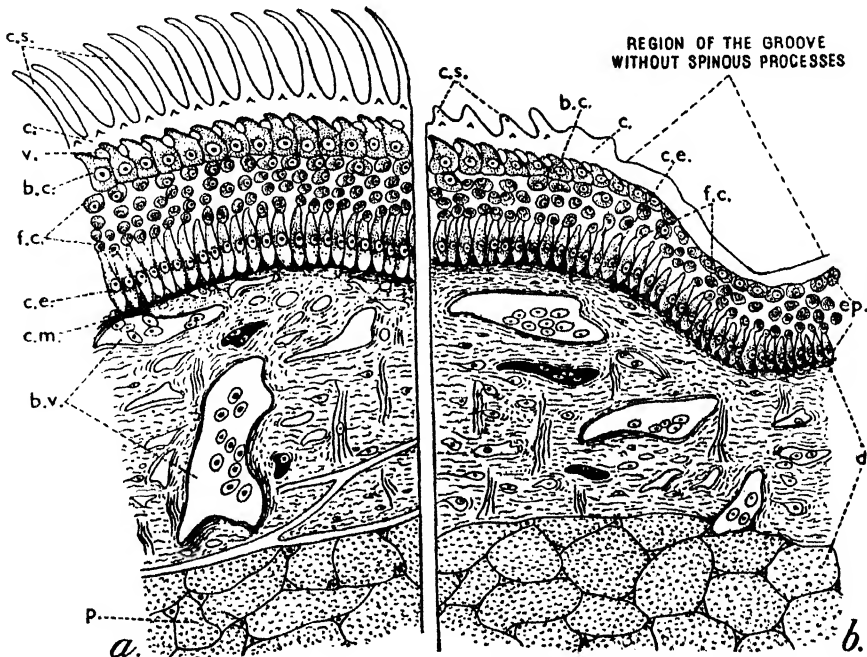
Several tiers of cells, derived from the epidermis, are present next to the epidermis. They are well-formed, oval cells, each having finely granular cytoplasm

and a centrally placed nucleus. They never combine to form a layer and are loosely scattered. They seem to behave like wandering cells. It is worth noticing that the cells nearer the epidermal layer are smaller, each cell bearing a small central nucleus, while cells further away, *i.e.*, cells in the outer tiers are large, and each



TEXT-FIG. 7.—*Glyptothorax telchitta* (Hamilton). Free-hand section of the adhesive pad, cut transversally to the skin plaits.

c., cuticle; d., dermis; ep., epidermis; s., spines.



TEXT-FIG. 8.—*Glyptothorax telchitta* (Hamilton). Transverse section of a ridged portion of the 'adhesive pad'.

a. Central part of the ridge; b. Edge of the ridge.

c. grooved part. b.c., beak-shaped cells; b.v., blood-vessels; c., cuticle; c.e., columnar epithelial cells; c.m., circular muscle layer; c.s., cuticular spine; d., dermis; ep., epidermis; f.c., formative cells; p., parenchyma; v., vacuole.

bears a large clear nucleus, with a well formed central nucleolus. These cells are being designated here as formative cells.

(c) *Beak-shaped cells.*

Cells of the outermost tier form a single row of squarish cells, each cell giving out at its free outer end a beak-shaped protoplasmic process. The cytoplasm within the main cell, as also in the process, is uniformly granular. Each cell has a centrally placed large clear nucleus, with a prominent central nucleolus. It is worthy of note that all the protoplasmic processes in this layer are directed one way, *i.e.*, towards the posterior side of the fish. In between the consecutive processes there are alternating vesicular spaces.

(d) *Cuticle and cuticular spines.*

Immediately next to the protoplasmic processes is a thin transparent, non-cellular covering layer, the cuticle, from which arise long spines. Both the spines and the cuticle take a mild stain. All the spines, like the protoplasmic processes of the underlying layer, are directed backwards. A careful counting reveals that there are as many spines in the section, as the underlying protoplasmic processes. The adhesive apparatus region is altogether devoid of receptors.

DISCUSSION.

Hora (1922, pp. 47-58) described a number of species in various stages of adaptations to swift water current and showed how the development of spines is correlated with the intensity of the current. He made a comparative study of similar adhesive apparatus in the hill-stream fishes of the order Cyprinoidae.

His description and figures of this part in *Bhavana annandalei* indicate that the material handled by him was not in a good state of preservation to enable him to determine the real epidermal layer. What he calls the basal epithelial cells is the epidermal layer proper. Most of the histological structures shown by him in his Text-fig. 19 on page 57, reproduced here as Text-fig. 9, are very similar to those figured in *G. telchitta* (Text-fig. 8) and his sketches interpreted on the lines of my findings become self-explanatory. Similar confusion exists about structures seen in *Garra*, where a superficial epidermal layer is described. The basal region, of which the cells are not well marked, is the real epidermis.

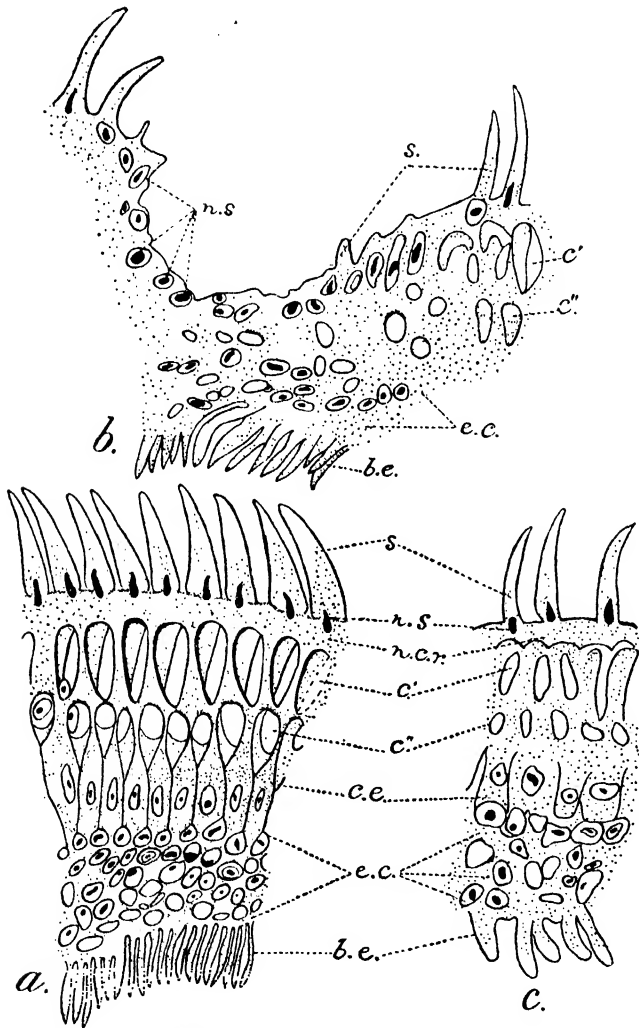
Among the Siluroidea, Hora studied the conditions seen in several species under the genus *Glyptosternum*. In *Glyptosternum labiatum* (Text-fig. 4), he missed locating the epidermis. Several layers of cells put together are labelled by him as epithelial cells. This figure studied on the lines suggested above will help to interpret rightly all the structures figured by him.

The conditions described by him in *Glyptothorax dorsalis*, page 55, are noteworthy. It is a resident of sluggish and muddy streams of the Manipur Valley, the spines, as a natural consequence, are small, and the spinous layer as a whole is not well developed. Here too the basal layer which is described by him as highly vacuolated is in reality the epidermis.

In *Glyptothorax madraspatanus*, the adhesive tissue is described by him as more advanced (p. 55), but the reasons put forward by him for this conclusion are not sound. He says, 'the adhesive tissue is more advanced in so far as the cell limits are not distinguished.' This condition is due to poor state of preservation of the tissue rather than to any kind of advancement in structure. Hora's own statements at two different places regarding the general make up of the adhesive apparatus tissue, where he says that the cell limits are not distinguishable, and that in the

basal epithelial layers he was not able to find any nuclei, support my assumption about the poor state of preservation of the materials handled by him.

In *Glyptothorax* sp., where the greatest specialization in the structure of the adhesive tissue within the genus is reached, Hora's interpretation of epidermis and its derivatives is based on an erroneous ground. His figure 19a of *Glyptothorax saisii* giving three sketches (Text-fig. 9) of the adhesive apparatus further confirms my findings. The real epidermal layer, recognized here too as basal layer has been given the least attention and it is stated to consist of cells without nuclei.



TEXT-FIG. 9.—*Glyptothorax* sp. Minute structure of the adhesive apparatus on the under surface. (Reproduction of Hora's Text-figure.)

a. transverse section through a portion of the ridge; b. transverse section through a portion of the groove; c. horizontal section through a portion of the ridge.

b.e., basal epithelial cells; c', first row of cavities; c'', second row of cavities; c.e., columnar epithelium; e.c., small rounded epithelial cells; n.c.r., non-cellular region; n.s., nucleus of the spine; s., spine.

Much more attention has been paid to the cells derived from the epidermis than to the real epidermis. Changes noticed by Hora, as to the structural differences between ridges and grooves are very similar to those observed by me in *Glyptothorax telchitta*.

Hora's findings regarding the general make up of the adhesive apparatus in various forms are very helpful. While his sketches showing the histological details are very useful, his interpretation of the different units that jointly form the adhesive apparatus, needs revision.

Wu and Liu's contribution on the structure of the adhesive apparatus of *Glyptosternum* (= *Glyptothorax*) (*Sinensia*, 1940) instead of adding to our knowledge something fresh, has added to the confusion of ideas about the structure and function of the apparatus. Their statement that the histological nature of it is practically unknown shows that they were completely ignorant of Hora's detailed investigations of this and similar other structures.

The entire epidermis and its derivatives are described by them as stratum germinativum, which, according to them, constitutes most of the epidermis, and consists of 8 to 10 cells layers. These layers are further described and labelled by them in their figures in the following manner:—

- (a) The deepest layer composed of elongated pyramidal cells is the basal layer.
- (b) It is overlapped by 3-4 layers of elongated spindle-shaped cells, which do not differ much from the cells of the basal layer.
- (c) Passing towards the surface, the cells are irregular polyhedral in shape, small at first, but larger in the succeeding layers. Some 4 to 5 rows of such cells are shown in the figure.
- (d) The most superficial layer is named as stratum corneum, and the cells in this layer are separated from each other, by intercellular spaces, which in turn are traversed by intercellular bridges.

At another place the layer stratum corneum is described by them as consisting of a single layer of cells. Owing to the disappearance of the intercellular spaces here the boundaries of cells are more or less in obscurity, the distinctive feature of this layer is that the free surface of its cells is fused, thickened and keratinized. That practically every cell at the ridged portion bears a spinule, seems to be of interest.

They have further described that the spinule, stained the same as the free border, is found to be a direct protrusion of the latter. It is really a modified part of the cell wall, a blind tube filled with cytoplasm.

At the base of each spinule is shown by them a clear pear-shaped space within which is figured an acute oval structure. They interpret the clear space as the position formerly occupied by the nucleus and the acute oval structure as the nucleolus, though they admit that its enormous size, somewhat renders this designation less convincing. They admit by saying 'We are not at present in possession of a definite idea concerning the real nature of this structure, but it is our belief that whatever this structure may be, it seems to be intimately correlated with the cornification of the stratum corneum.'

As to the function of this structure, it is regarded by them less adhesive than protective.¹ The deficiency of the goblet cells apart from the cornification and spinule formation of the free border of the epidermis led them to believe so.

They further believe that the chest of this fish is liable to friction when it perches, as it used to be on rocks or stones, and there is much need of a structure to protect this scaleless region against mechanical influence. Although

¹ Italics are mine.

they conclude by saying that the spinules might act as numerous small pegs to help the fish resting more steadily upon the substratum under swift currents, they feel at the same time that *this apparatus cannot subjectively effect adhesion* as performed by the mouth of Cyclostomata, sucking disc of *Lepidogaster*, paired fins of *Sinogastromyzon* and ventral fins of *Gobius* seems beyond all doubt. It will be readily admitted that the adhesive disc of *Glyptothorax* does not function as a sucking disc of the fishes referred to by Wu and Liu, but acts as a frictional device for increasing adhesion to the substratum.

Although Wu and Liu (1940) adopted very elaborate micro-technique, they were not able to ascertain rightly the histological details of the different parts of the disc in their preparation. Their work unfortunately sheds very little light on the point. It is apparent that their observations on some of the points are mistaken, while those of Hora are correct. Unfortunately their description and diagrams of the adhesive disc are based on an incomplete appreciation of the details of its structure and are therefore not very helpful.

PROBABLE ORIGIN OF ADHESIVE PAD.

(Text-fig. 10.)

A close study of the successive stages of series of microtome sections reveals the way different elements that form the adhesive disc are developed from a simple columnar epithelium. It is the perching habit which tends to bring about mechanical devices that help the fish to maintain its position against strong currents.

In the beginning there is a simple epidermis consisting of a single layer of columnar epithelium, with a thin covering of cuticle. Cuticle is the layer exposed to great stress and strain, and it must therefore exert both physical and mechanical means to gain fixed points for maintaining a position. Cuticle gets modified into large spines, which act as pegs. It gets torn at times and is very soon replaced by fresh cuticular covering. This regeneration of cuticle is made possible by the underlying epidermal cells and its derivatives.

Text-figure 8 shows how the epidermal cells get modified to form the cuticular spines, and the way cuticular layer regenerates.

Epidermis consists of a single layer of columnar epithelial cells, and there is a thin layer of cuticle (Text-fig. 10a). Epidermal cells are in active state of mitotic division and give rise to formative cells, i.e., cells which ultimately form the cuticle. The first series of formative cells form a layer beneath the cuticle, and fresh cells that arise from the epidermis remain in reserve in several tiers (Text-fig. 10 b, c, d, e) those close to the epidermal cells are the smallest of the series.

Perching habit makes the cuticle project beyond the surface level, and each projection is a cuticular spine. This projection is initiated by the underlying layer of cells, each cell giving out a protoplasmic process which give the cells in this layer beak-shaped appearance. Text-fig. 10f shows the formation of small spinules, and at the base of each spinule there is the projecting protoplasmic process of the underlying cell.

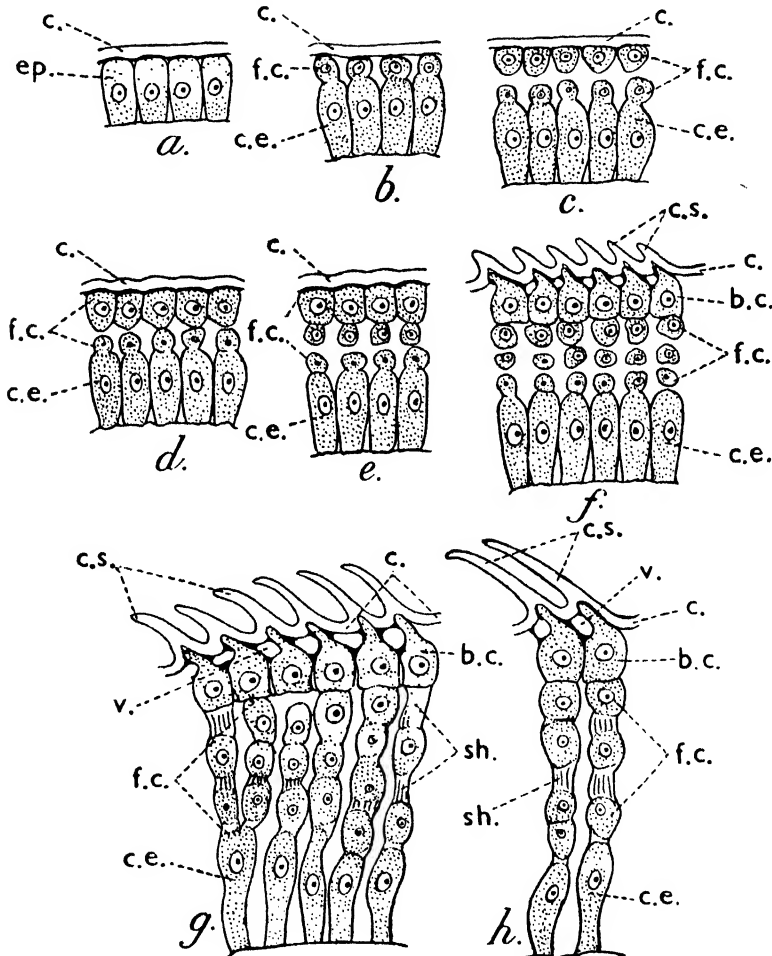
As a result of mitotic division of the epidermal cells there is a constant supply of formative cells, which at times remain ensheathed in a chain from the place of their origin to underneath the cuticle (Text-fig. 10 g, h).

It has been noticed in the preparations that at places, where the cuticular layer gets torn off, the protoplasmic processes of cells of the underlying layer take the place of cuticular spines till fresh cuticle is regenerated. Wu and Liu's illustrations appear to have been taken from preparations where cuticular layer is not present, and spinules are only the protoplasmic processes of the underlying cell layer.

FUNCTION OF THE DIFFERENT PARTS.

The anterior and posterior lips, the maxillary barbels, the region of the branchiostegial rays and the adhesive pad, all perform an adhesive function. The papillated regions of the two lips perform it by adpression, and the region of the branchiostegial rays by means of the cuticular spines. All the three regions have a relatively less adhesive power than that of the specialized adhesive disc.

General structure of the adhesive disc, total absence of receptors in this region, the long cuticular spines, and the way cuticle is regenerated, leave no doubt in my mind as to its being adhesive.



TEXT-FIG. 10.—*Glyptothorax telchitta* (Hamilton). Developing stages of the 'adhesive pad'.

a. Stage with single layer of columnar epithelium; b. Stage showing the birth of the formative cells from the epithelium; c. Stage showing the birth of a reserve layer of formative cells; d. Stage showing the reserve layer of formative cells fusing to form the cuticle; e. Stage showing the formative cells joined with the first tier of formative cells and the birth of another layer; f. Stage showing formation of small spinules; g. & h. Stages showing the formative cells ensheathed in chains.

b.c., beak-shaped cells; c., cuticle; c.e., columnar epithelial cells; c.s., cuticular spines; ep., epidermis; f.c., formative cells; sh., sheath; v., vacuole.

Wu and Liu's view that adhesive apparatus cannot subjectively effect adhesion and that the spinules are less adhesive than protective is at best a conjecture without much observational or experimental evidence.

Long spines, all directed one way, behave like pegs, and these devices, helped by large number of teeth on the two jaws, all combined, form very efficient adhesive organs.

ABSTRACT.

This paper, part I of the series, deals with the epidermal organs which serve adhesive function in a small catfish *Glyptothorax telchitta* found in fast flowing streams of the Rihand River, Mirzapore, U.P. Due to the resistance offered by the fish against strong water currents, a number of epidermal adhesive devices are developed in it which help the fish to maintain a more or less stationary position in fast running waters.

These are:

- (a) *The Rostral hood, i.e.,* the region in front of the mouth, which is secondarily formed and covers the anterior lip. It is in the form of a pad and is profusely papillated subserving an adhesive function.
- (b) *The posterior lip* region is also papillated and these papillae are longer than those of the rostral hood.
- (c) A pair of *maxillary barbels*—also help in the process of adhesion.
A large number of Receptors are present on the Rostral hood, the posterior lip, and on the maxillary barbels.
- (d) The region of the *Branchiostegial rays* has a grooved integument which bears short stout spines.
- (e) In the *Thoracic adhesive apparatus* the integument of the ventral chest region has a marked rhomboidal area which is longitudinally pliated. The ridges are provided with long curved cuticular spines which help the fish to stick to the substratum. This region is devoid of receptors.

LITERATURE.

- Hora, S. L. (1921). Indian Cyprinoid fishes belonging to the genus *Garra*. *Rec. Ind. Mus.*, **22**, 635, 643.
- (1922). Structural modifications in the fish of Mountain Torrents. *Rec. Ind. Mus.*, **24**, 46–58.
- (1923). Observations on the fauna of certain Torrential streams in the Khasi Hills. *Rec. Ind. Mus.*, **25**, 579–598.
- (1930). Ecology, Bionomics and evolution of the Torrential fauna, with special reference to the organs of attachment. *Phil. Trans. Royal Soc. London (B)*, **218**, 171–282.
- Wright, R. Ramsay (1884). On the skin and cutaneous organs of *Amiurus*. *Proc. Canadian Inst. (n.s.)*, **2**, 254–255.
- Wu, H. W. and Liu, C. K. (1940). On the structure of the 'Adhesive Apparatus' of *Glyptosternum*. *Sinensia*, **11**, 69–75.

CYTOLOGICAL INVESTIGATION OF THE MANGO (*MANGIFERA INDICA* L.) AND THE ALLIED INDIAN SPECIES.

By SUNIL KUMAR MUKHERJEE, D.Sc., Botany Department, Delhi University.¹

(Communicated by Dr. P. N. Bhaduri, M.Sc., Ph.D., F.N.I.)

(Received May 22 ; read August 4, 1950.)

INTRODUCTION.

The mango, which is one of the most important tropical fruits, has more than a thousand varieties in India, all of which belong to one species, *Mangifera indica* L. About two dozen of these are of much commercial importance, and are maintained in cultivation through vegetative propagation by grafting. They differ from one another mainly in fruit characters, and a few other minor features, e.g. colouration of the emerging leaves, colouration and pubescence on the panicle branches, etc. (Mukherjee, 1948 b). Of the 41 species included in the genus *Mangifera* distributed throughout Malaysia, only three are reported from India: (1) *M. indica* L., (2) *M. khasiana* Pierre (a species of doubtful occurrence), and (3) *M. sylvatica* Roxb. (Mukherjee, 1949).

Available information on the cytogenetics of species of Anacardiaceae and especially on the genus *Mangifera* L. is very meagre. Chromosome number has been reported so far only for *Mangifera indica*. Maheshwari (1934) first reported the number doubtfully as $n = 24-26$, and Roy (1939) published the haploid number of four varieties as ranging between $n = 6-8$. Recently Janaki Ammal (1945) has mentioned the number as $2n = 40$.

Due to want of knowledge on the cytogenetics of such an important tropical fruit tree, the present investigation was undertaken to elucidate the cytological basis of variation in the mangoes (*M. indica*) and the allied species, and to find out their mode of origin and correlate their inter-relationships.

MATERIALS AND METHODS.

The present investigation includes observations on three species—*M. indica* L. (including 23 cultivated varieties and 1 wild type), *M. sylvatica* Roxb., and *M. caloneura* Kz., which are available in India. Other species of the genus, occurring in the Malaysian region, could not be secured for examination during this investigation (1943-46), due to World War II. The materials of the cultivated varieties of mango were obtained from the Government Horticultural Research Stations in Bengal, Bihar and Madras, while the wild races of *M. indica* and *M. sylvatica* were collected from the forests of Chittagong Hill Tracts (near Burma border) and Assam respectively. Flower-buds of *M. caloneura* Kz., a Burmese species, had been collected from a planted tree in the Royal Botanic Garden, Calcutta. The seeds obtained from the plant did not germinate.

For a study of the morphology of somatic chromosomes, root-tips were collected from seedlings, raised in pots containing sand at bottom and soil above. The seeds

¹ The investigation was conducted in the Botanical Laboratory of the Calcutta University under the scheme on 'Cytogenetics of Mango' financed by the Indian Council of Agricultural Research.

TABLE I.

Comparative statement of chromosome number, number of satellites, secondary constrictions and nucleoli.

Name.	Chromosome number.		Number of satellites and secondary constrictions.				Total No. of SAT. and S.C.	Maximum number of nucleoli in each dyad nucleus.
			Definite.		Doubtful.			
	2n	n	SAT.	S.C.	SAT.	S.C.		
<i>M. sylvatica</i>	40	20	4	4	2	2	12	—
<i>M. caloneura</i>	—	..	—	—	—	—	—	5
<i>M. indica</i> —								
(a) Wild type	—	..	—	—	—	—	—	8
(b) Cultivated varieties:								
1. Shadwalla	40	..	4	6	—	2	12	—
*2. Himsagar .. ..	..	..	2	8	—	4	14	8
*3. Kishenbhog .. ..	..	..	4	4	—	—	8	4
*4. Golapkhas .. ..	..	..	4	6	—	2	12	—
5. Rogni .. ..	..	..	4	4	—	2	10	5
*6. Langra .. ..	..	..	6	4	—	2	12	6
7. Anupam .. ..	..	..	4	6	—	—	10	5
8. Kalapahar	40-42	..	4	8	—	—	12	—
9. Safdar Pasand	40-41	..	4	6	—	2	12	—
10. Laskarshikhan	40	..	2	6	—	4	12	8
11. Sah Pasand	—	..	—	—	—	—	—	6
12. Jehanara	40	..	4	4	2	—	10	—
13. Lakhua .. ..	..	..	4	4	—	4	12	—
14. Kohitur .. ..	..	..	4	4	—	2	10	5
*15. Bombai .. ..	..	..	4	6	2	2	14	4
*16. Fazli .. ..	..	..	4	4	2	4	14	—
*17. Alphonso .. ..	..	..	4	4	—	—	8	6
18. Panja Pasand .. ..	..	..	4	4	—	2	10	5
*19. Daseri (aman) .. ..	..	..	4	4	—	—	8	4
20. Kurukkan .. ..	..	..	4	4	—	—	8	9
*21. Pairie (Poona) .. ..	..	..	4	6	—	—	10	—
22. Latra (creeping)	40-41	..	2	10	—	4	16	—
23. Baramassia	—	..	—	—	—	—	—	8
24. Kaitki	—	..	—	—	—	—	—	6

* indicates important commercial varieties.

— indicates undetermined.

SAT indicates satellited chromosomes.

S.C. indicates secondary constricted chromosomes.

of *M. sylvatica*, which did not germinate under usual conditions, were forced by alternate treatment with heat and cold.

Desired root-tip preparations were made from materials fixed at 9-11 a.m. in a mixture of 1% chromic acid and 10% formalin in a proportion of 6:4. Paraffin sections, 8-10 μ thick, were stained by Newton's Iodine Crystal-Violet method.

Flower-buds of the same varieties and species were fixed in Belling's Nawashin fluid between 9-11 a.m. after a pretreatment in Carnoy's fluid. Paraffin sections, 16-18 μ thick, were stained in Crystal Violet after premordanting in Nawashin's fluid.

The smear method for PMC did not prove successful, due to the rapid and successive division of the nuclei in the single fertile stamen. Moreover, the flower buds are so small and so much aggregated while young, that it becomes very difficult to dissect out the proper type of bud and the anther contained in it without the help of a dissecting microscope.

TABLE II.

Size variation in chromosomes of individual complement and their total length.

Name.	No. of chromosomes of different lengths and their total length.			Total length of metaphase chromosomes per nucleus.
	0.4-1 μ (short).	1.0-1.5 μ (medium).	1.5-2.0 μ (long).	
<i>M. sylvatica</i>	{ 30 22.5 μ	10 12.5 μ	.. ..	35 μ
<i>M. indica</i> varieties—				
1. Shadwalla	{ 22 16.5 μ	12 15 μ	6 10.5 μ	42 μ
2. Himsagar	{ 24 18 μ	12 15 μ	4 7 μ	40 μ
3. Kishenbhog	{ 30 22.5 μ	6 7.5 μ	4 7 μ	37 μ
4. Golapkhas	{ 28 21.0 μ	10 12.5 μ	2 3.5 μ	37 μ
5. Rogni	{ 24 18 μ	14 17.5 μ	2 3.5 μ	39 μ
6. Langra	{ 28 21 μ	10 12.5 μ	2 3.5 μ	37 μ
7. Anupam	{ 32 24 μ	8 10 μ	.. ..	34 μ
8. Kalapahar	{ 22 16.5 μ	14 17.5 μ	4 7 μ	41 μ
9. Safdar Pasaud	{ 24 18 μ	12 15 μ	4 7 μ	40 μ
10. Laskarshikhan	{ 22 16.5 μ	12 15 μ	6 10.5 μ	42 μ
11. Jehanara	{ 28 21 μ	12 15 μ	.. ..	36 μ
12. Lakhna	{ 28 21 μ	12 15 μ	.. ..	36 μ
13. Kohitur	{ 28 21 μ	10 12.5 μ	2 3.5 μ	37 μ
14. Bombai	{ 24 18 μ	12 15 μ	4 7 μ	40 μ
15. Fazli	{ 26 19.5 μ	12 15 μ	2 3.5 μ	38 μ
16. Alphonso	{ 28 21 μ	10 12.5 μ	2 3.5 μ	37 μ
17. Panja Pasand	{ 26 19.5 μ	12 15 μ	2 3.5 μ	38 μ
18. Daseri	{ 28 21 μ	10 12.5 μ	2 3.5 μ	37 μ
19. Pairie	{ 26 19.5 μ	10 12.5 μ	4 7 μ	39 μ
20. Latra	{ 18 13.5 μ	18 22.5 μ	4 7 μ	42 μ

The above calculations are based on average length of the 'short' chromosomes as 0.75 μ , 'medium' as 1.25 μ and 'long' as 1.75 μ , e.g. if there are 12 chromosomes of 'medium' length group, the total length has been put as 15 μ .

Observations and drawings were made, using principally a Zeiss 2 mm. apochromatic objective 1.4 N.A., and an apochromatic condenser 1.4 N.A., with homogeneous immersion and compensating eyepieces $\times 10$ and $\times 18$, and a Zeiss drawing prism.

OBSERVATIONS.

Chromosome number.—The three species under investigation are morphologically very much allied; *M. sylvatica* being distinguished mainly by its glabrous panicle and acuminate beaked fruits, whereas *M. caloneura* differs from *M. indica* in bigger lax flowers and compressed round fruits. The leaves of the three species are almost similar, but in the cultivated varieties of *M. indica* the petiole is shorter, whereas in the wild type it is longer and almost of the same length as in *M. sylvatica*, with which it is more allied. The varieties of mango (*M. indica*) and the allied species examined, show a remarkable stability in their chromosome number, all possessing $2n = 40$ and $n = 20$ chromosomes. In three varieties (*Kalapahar*, *Sajdar Pasand* and *Latra*) only, plates (Fig. 22) showing an aberration in their somatic chromosome number (41 and 42) have been found. The results are given in Table I.

Karyotype analysis.—A critical study of the chromosome morphology shows that *M. sylvatica* and the varieties of *M. indica* differ from one another in the size variation of the chromosomes (cf. Table II), and the total number of satellites and secondary constrictions in their complements (cf. Table I). The satellites in some of the chromosomes are extremely small. Due to the short length of the chromosomes, the secondary constrictions indicated by the unstained gaps, become obscure whenever there is a slight swelling or torsion of the chromosomes. Identity of some of the secondary constrictions, therefore, appears doubtful. Determination of the morphology of somatic chromosomes therefore becomes difficult, especially because few well spread-out plates are present in the small cells within the short cortical region of the root-tip. Moreover, the cell-inclusions, mainly of the nature of tannins in the outer cortical zone, interfere very much with the fixing and staining of the chromosomes. The number of satellites and secondary constrictions present in the different chromosomes of a complement, has therefore been determined after an examination of more than 10 good somatic plates.

The chromosomes varying in length between 0.4μ – 2.0μ , have been classified under 3 main length-groups—*Short* (0.4 – 1.0μ), *Medium* (1.0 – 1.5μ) and *Long* (1.5 – 2.0μ). A comparative statement of chromosome morphology according to length-variation in the different types is given in Table II.

Apart from this broad grouping according to size-differences, the somatic chromosomes could be distinguished by their morphology into the following 11 categories:—

- Type A. Long chromosomes with both secondary constrictions and satellites.
- Type B. Long chromosomes with submedian primary constriction and a typical satellite at the end of the longer arm.
- Type C. Long chromosomes with submedian primary constriction and subterminal or submedian secondary constriction on the longer arm.
- Type D. Medium chromosomes with submedian primary constriction and a satellite with short or long threads at the end of the longer arm.
- Type E. Medium chromosomes with a satellite at the end, but without any apparent primary constriction.
- Type F. Medium chromosomes with submedian primary constriction and subterminal or median secondary constriction on the longer arm.
- Type G. Medium chromosomes with median or submedian primary constriction.
- Type H. Short chromosomes with submedian primary constriction and a fine satellite on the longer arm.

Type I. *Short chromosomes with a satellite at one end and without any apparent primary constriction.*












Type J. *Short chromosomes with median or submedian primary constriction.*

Type K. *Short chromosomes without any apparent constriction.*

Of the 11 chromosome types, mentioned above, all except G, J and K are nucleolar, i.e., possess satellites or secondary constrictions. An analysis of the somatic chromosome complement of the different species and varieties indicates the following idiogram:—

TABLE III.

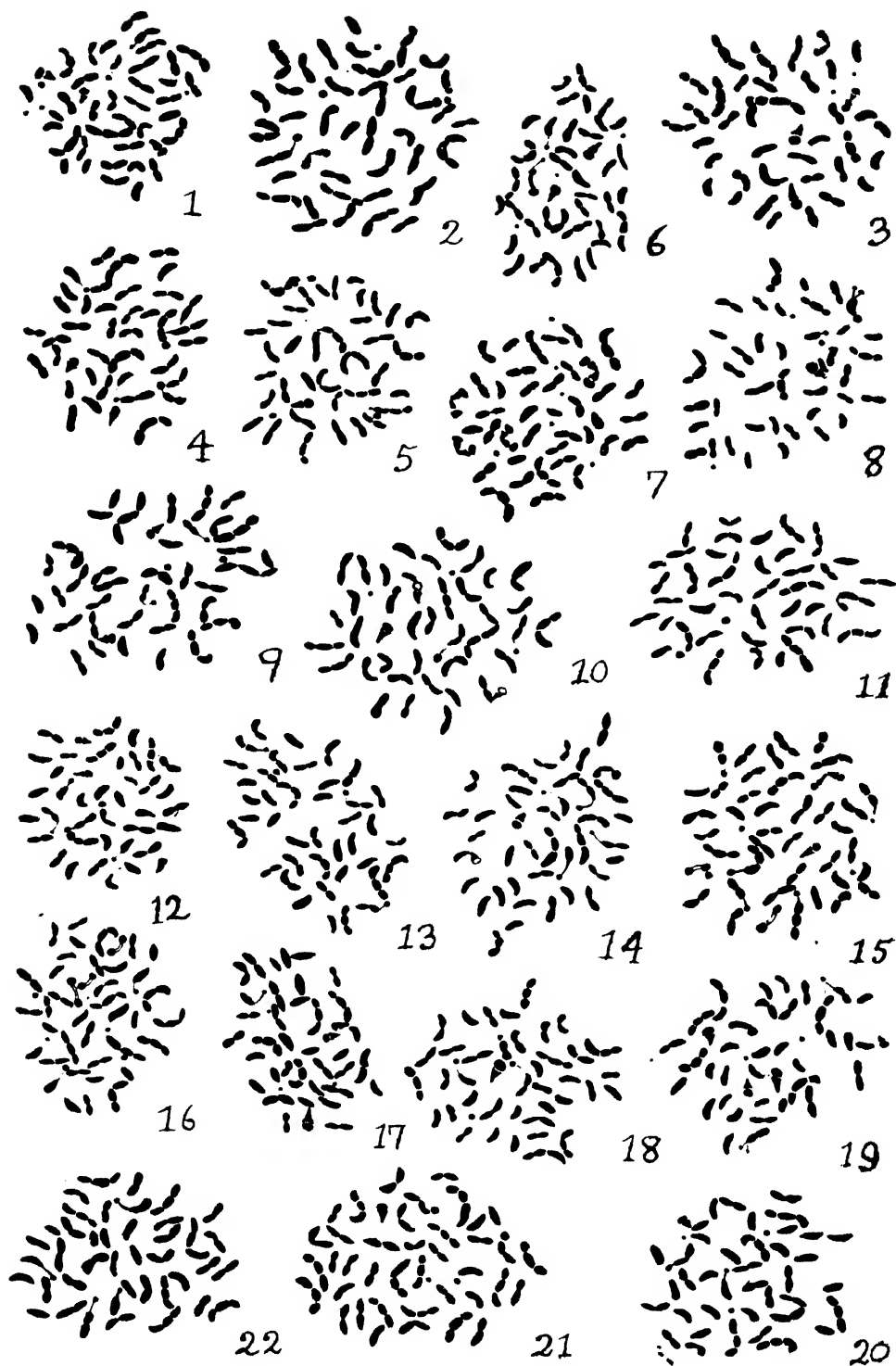
A comparative account of Karyotypes, observed in the mangoes and the allied species.

Name of varieties and the number of nucleoli.			Chromosome types.										
			A	B	C	D	E	F	G	H	I	J	K
													
(8)	1. Kishenbhog ..	..	..	..	4	2	2	..	2	..	..	18	12
	2. Alphonso ..	..	..	..	2	2	..	2	6	..	2	6	20
	3. Daseri ..	..	..	..	2	2	..	2	6	..	2	6	20
(10)	4. Rogni ..	..	..	..	2	2	2	4	6	..	..	12	12
	5. Kohitur ..	..	..	..	2	2	2	4	2	..	..	14	14
	6. Panja Pasand ..	..	..	..	2	2	2	4	4	..	..	10	16
	7. Pairio ..	..	..	..	4	..	4	2	4	..	..	14	12
	8. Anupam ..	..	..	..	..	2	..	6	..	..	2	18	12
	9. Jehanara ..	..	..	..	..	4	2	4	2	..	..	10	18
(12)	10. Shadwalla ..	..	..	2	4	2	..	4	6	..	..	16	6
	11. Golapkhas ..	..	..	..	2	2	2	6	..	..	..	20	8
	12. Langra ..	..	..	..	2	4	..	4	2	2	..	20	6
	13. Kalapahar ..	..	..	..	4	4	..	4	6	..	..	12	10
	14. Safdar Pasand ..	..	..	..	4	4	..	4	4	..	..	12	12
	15. Laskarshikhan ..	..	..	..	6	2	..	4	6	..	..	12	10
	16. Lakhna ..	..	..	..	..	4	..	8	..	..	..	12	16
(14)	<i>M. sylvatica</i> ..	..	..	..	..	2	2	6	..	..	2	18	10
	17. Himsagar ..	..	..	..	4	..	2	8	2	..	..	14	10
	18. Bombai ..	..	2	..	2	4	..	6	2	..	..	18	6
	19. Fazli ..	..	..	..	2	2	2	6	2	..	2	12	12
(16)	20. Latra ..	..	..	..	4	4	..	8	6	..	..	12	6

In the above table the species and the varieties have also been grouped under 5 classes according to the number of nucleolar chromosomes (8, 10, 12, 14 or 16). An examination of the table shows the following characteristic features.

Alphonso and *Daseri* (Figs. 17 and 19) have exactly similar chromosomes. They have the same total length of metaphase chromosomes as in *Kishenbhog*, *Rogni*, *Kohitur* and *Panja Pasand* (Figs. 6, 14 and 18) have the same number of C, D, E and F chromosomes. *Anupam* (Fig. 8) has the highest number (32) of 'short' chromosomes in the '10 nucleolar chromosome group'.

Shadwalla (Fig. 2) is conspicuous in having 2B chromosomes with prominent big SATs. *Golapkhas* (Fig. 5) has 2E chromosomes which are absent in other varieties of the '12 nucleolar chromosome' group. *Langra* (Fig. 7) is characteristic in having sharp primary constrictions in majority of the chromosomes, whereas in most of the other varieties much higher number of chromosomes are without any sharp primary constriction. *M. sylvatica* (Fig. 1) is characterized by the absence of



(For Explanation, see p. 293.)

'long' chromosomes and by the possession of a high number (30) of 'short' chromosomes.

Among the types having 14 nucleolar chromosomes, *Bombai* (Fig. 15) is characterized by a pair of A chromosomes, which have both satellites and secondary constrictions. *Latra* the mango with trailing branches has the highest number of nucleolar chromosomes (i.e., SATs and secondary constrictions) among the mangoes examined (Fig. 21).

Maximum number of nucleoli from Dyad nuclei.—The number of nucleoli in each dyad nucleus in PMC (Table I) varies between 4 and 9 (Figs. 45–57). They have definite size difference and may be recognized as *big*, *intermediate* and *small*. These three types of nucleoli are present in different numbers in different varieties, but they are found to be segregated into homomorphic pairs in the two nuclei in a dyad cell, indicating a regular disjunction of homologous pairs of satellited and secondary constricted chromosomes.

The number of satellited and secondary constricted chromosomes are generally found to be the same as the total number of nucleoli in the two nuclei of a dyad cell. There are some anomalies in this correlation, the number of nucleoli being less in *Bombai* (Fig. 51) and higher in *Himsagar*, *Laskarshikhan*, *Kurukkan* (Figs. 46, 47 and 57). In the former types, the anomaly in correlation may be due to the fusion of two or more nucleoli just after formation in early telophase, which stage passes off very quickly.

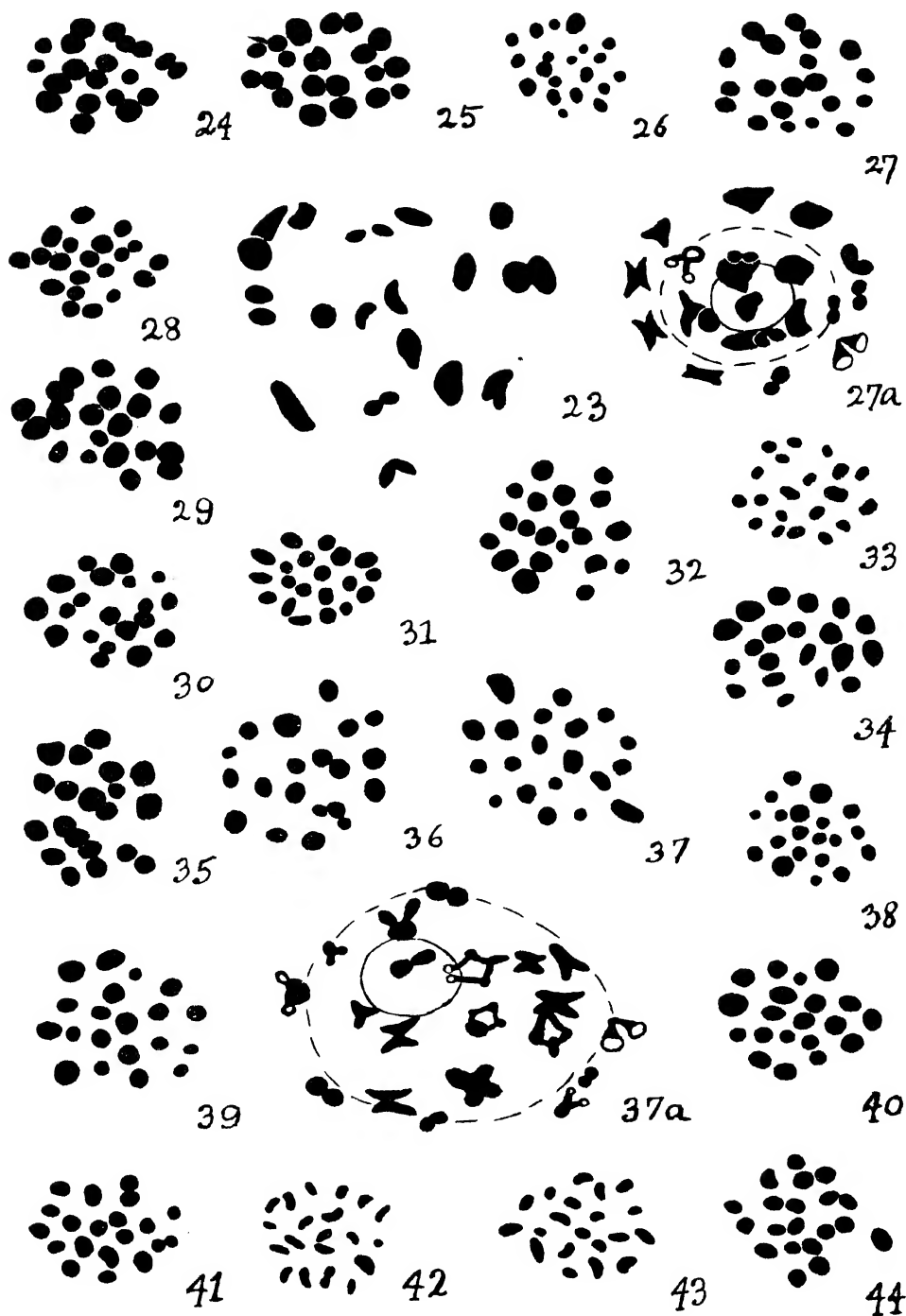
The early fusion of nucleoli is indicated by their occurrence in varying numbers in different dyad nuclei within the same slide, although the total nucleolar volume in those nuclei remains almost the same. On the other hand, the occurrence in some varieties of higher nucleolar number than the observed number of satellited and secondary constricted chromosomes is most probably due to the difficulty in tracing out all the SATs and secondary constrictions present, specially when these constrictions are super-numerary in nature, i.e., a single chromosome having more than one nucleolar constriction. However, in all cases the maximum number of nucleoli have been taken into consideration, as that is a surer guide to the determination of the number of nucleolar constrictions (Bhaduri 1944, 1947; Chakravorti 1948).

Meiosis in pollen mother cells.—The varieties of *M. indica* and the allied species, *M. sylvatica* Roxb. and *M. caloneura* Kz. are characterized by having well-developed anthers in only 1 of the 5 stamens.

Along with the development of the flower-bud the anther grows in size and follows a normal course of development leading to the differentiation of the pollen mother cells with a big nucleus. After usual changes in the PMC nuclei, the homologous chromosomes are found to pair into 20 clear bivalents, which arrange themselves mostly below the nuclear membrane and around the persisting nucleolus during diakinesis (Figs. 27a and 37a). The nuclear membrane and the nucleoli subsequently disappear along with the formation of a spindle, at the equator of which the bivalents are arranged. A polar view of the metaphase plates gives a clear picture of 20 bivalents, which are found to be aggregated into groups of 4, 3 and 2 due to secondary association (Figs. 24, 25, 29 and 35). Data regarding grouping of bivalents, which indicate secondary association of distant homologues, are given in Table IV. It clearly shows that the maximum association of bivalents is into 8 groups or units, and the most frequent association is 10.

FIGS. 1–22. Somatic chromosome plates during metaphase: (see p. 292).

1. *M. sylvatica*. 2–22. Varieties of *M. indica*. 2. Shadwalla. 3. Himsagar. 4. Kishenbhog. 5. Golapphas. 6. Rogni. 7. Langra. 8. Anupam. 9. Kalapahar. 10. Safdar Pasand. 11. Laskarshikhan. 12. Jehanara. 13. Lakhna. 14. Kohitur. 15. Bombai. 16. Fazli. 17. Alphonso. 18. Panja Pasand. 19. Dasari. 20. Pairie. 21. *Latra* (creeping mango). 22. Kalapahar with 42 chromosomes. All drawings $\times 4,200$.



(For Explanation, see p. 295.)

TABLE IV.

Comparative data regarding Secondary Association.

Names of Sp. and Vars.	Maximum Association.	Most frequent Association.
<i>M. caloneura</i> Kz. ..	*2(3)+7(2) = 9	2(3)+6(2)+2(1) = 10
<i>M. indica</i> Linn.—		
'wild' type ..	2(3)+7(2) = 9	2(3)+6(2)+2(1) = 10
Var. Shadwalla ..	2(3)+6(2)+2(1) = 10	2(3)+6(2)+2(1) = 10
.. Kishenbhog ..	4(3)+4(2) = 8	2(3)+6(2)+2(1) = 10
.. Langra ..	2(3)+6(2)+2(1) = 10	2(3)+6(2)+2(1) = 10
.. Anupam ..	2(3)+6(2)+2(1) = 10	2(3)+6(2)+2(1) = 10
.. Safdar Pasand ..	1(4)+2(3)+4(2)+2(1) = 9	3(3)+4(2)+3(1) = 10
.. Laskarshikhan ..	1(4)+3(3)+3(2)+1(1) = 8	1(4)+7(2)+2(1) = 10
.. Bombai ..	2(3)+6(2)+2(1) = 10	2(3)+6(2)+2(1) = 10
.. Fazli ..	1(4)+2(3)+4(2)+2(1) = 9	3(3)+4(2)+3(1) = 10
.. Alphonso ..	4(3)+4(2) = 8	2(3)+6(2)+2(1) = 10
.. Panja Pasand ..	2(3)+7(2) = 9	2(3)+6(2)+2(1) = 10
.. Daseri (aman) ..	4(3)+4(2) = 8	2(3)+6(2)+2(1) = 10
.. Kurukkan ..	3(3)+4(2)+3(1) = 10	3(3)+4(2)+3(1) = 10
.. Sah Pasand ..	3(3)+4(2)+3(1) = 10	2(3)+6(2)+2(1) = 10

* 2(3) means 2 groups of 3 bivalents in each group, etc.

After complete terminalization of the chiasmata in paired bivalents during metaphase, their regular disjunction takes place resulting in the separation of 20 homologous chromosomes towards the two poles. While moving to the two poles during anaphase, the chromosomes always appear at equal distances from the equator of the spindle on the two sides. During this process, no indication of multivalent formation or any other meiotic irregularity such as chromosome bridges, lagging chromosomes, etc., is seen.

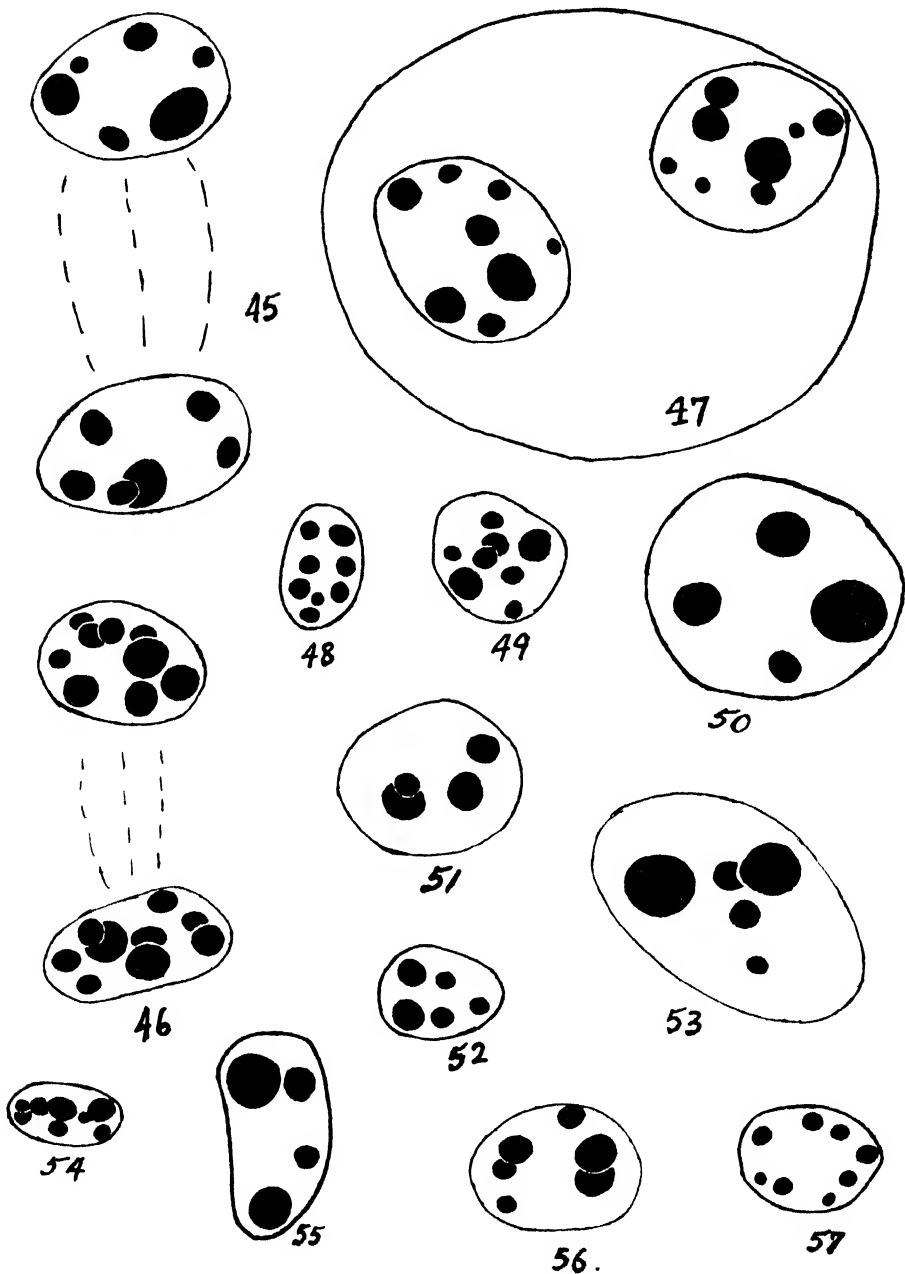
The chromosomes ultimately reach the two poles during telophase, and give rise to the nucleoli at the region of nucleolar organizers, i.e., SAT threads and secondary constrictions. Due to the small volume of the nucleus and the presence of a high number of satellited and secondary constricted chromosomes in it, the maximum number of nucleoli could not be clearly determined in every case. They become very clear during the short interphase stage when they take a bright stain. It is obvious therefore that the maximum number of nucleoli, present in a nucleus, can only be observed in preparations where such favourable stages are present (Bhaduri and Kar, 1948).

Second division and cytokinesis.—After a short period of rest during interphase succeeding meiotic division, the subsequent mitotic division of the chromosomes begins in the two nuclei within the single dyad cell. The configuration of the two spindles is not regular, and they appear parallel or at right angles to each other. After this second division 4 separate nuclei are formed, which remain enclosed within

FIGS. 23–44. Chromosome plates during meiosis: (see p. 294).

23. Diakinesis in *M. sylvatica* (scattered drawing). 24–44. Metaphase plates. 24. *M. caloneura*. 25. *M. indica* (wild race). 26–44. *M. indica* (horticultural varieties). 26. Shadwalla. 27. Himsagar. 27a. Himsagar (Diakinesis). 28. Kishenbhog. 29. Langra. 30. Anupam. 31. Kalapahar (Second Division). 32. Safdar Pasand. 33. Sah Pasand (Second Division). 34. Kohitur. 35. Laskarshikhan. 36. Bombai. 37. Kurukkan (polyembryonic variety). 37a. Kurukkan (Diakinesis). 38. Baramassia. 39. Latra. 40. Pairie. 41. Daseri. 42. Panja Pasand. 43. Alphonso. 44. Fazli (41–44. Second division metaphase plates).

Figs. 26, 33, 42 and 43 ($\times 3,600$); rest $\times 4,200$.



FIGS. 45-57. Nucleoli during Telophase in Dyad and Tetrad cells in *M. indica* :

45. Kaitki. 46. Kurukkan. 47. Himsagar. 48. Wild race (Tetrad). 49. Kishenbhog (somatic cells). 50. Kishenbhog. 51. Bombai. 52. Anupam (Tetrad). 53. Rogni. 54. Baramassia (Tetrad). 55. Daseri. 56. Sah Pasand. 57. Laskarshikhan (Tetrad). All drawings $\times 4,200$.

the common wall of the PMC. Subsequently the cytoplasm within the PMC divides by furrowing, and produces a wall around each of the 4 tetrad nuclei, leading to the formation of 4 microspores which are liberated after bursting of the anther when the flower opens.

Pollen grains.—The mature pollen grains in all the varieties show similar morphology in their elliptic shape and in having a closely pitted exine with 3 long, tapering sharply defined furrows (*tricolpate type*) containing a large germ-pore at the centre of each. They are also similar in size, varying generally between 24–30 μ in average diameter.

The pollen grains are mostly normal and full of cytoplasm; only a few (1.8–12.0%) are crumpled or empty, indicating evident signs of negligible amount of male sterility. Experiments at Poona (Burns and Prayag, 1921), Sabour (Sen, 1943), and U.S.A. (Sturrock, 1944) have also shown that the varieties are readily inter-crossable, indicating close compatibility among them.

The cytological findings indicate normal development of the grains and close compatibility between the varieties.

DISCUSSION AND GENERAL CONCLUSION.

Stability in chromosome number in Mangifera L.—A reference to the list of chromosome numbers of plants (Darlington and Ammal, 1945) shows that species comprising a genus have generally a varying series of chromosome numbers; rarely they possess the same chromosome number throughout a genus. Examples of such stability in chromosome number are found in *Antirrhinum* (14 sp. examined, $2n = 16$), *Aloe* (73 sp., $2n = 14$), *Quercus* (44 sp., $2n = 24$), *Ribes* (21 sp., $2n = 16$), *Ficus* (29 sp., $2n = 26$), *Erica* (6 sp., $2n = 24$), etc.

The present investigation shows that all the 3 sp. of *Mangifera* (*M. indica*, including the wild and cultivated varieties; *M. sylvatica* and *M. caloneura*) have the same chromosome number, $2n = 40$ and $n = 20$. The chromosome numbers of other species of the genus are not yet known.

The genus has been split into two sections, according to the presence or absence of the disc (Mukherjee, 1949). 'Section I' having well-developed swollen disc contains 34 species, and 'Section II' with disc reduced or absent contains 7 species. Only two species possess 10 stamens, of which 5 are fertile, 4 species have all the 5 stamens fertile, 1 species has 3 stamens fertile, while the remaining 34 species have only 1 of the 5 stamens fertile. The three species under investigation belong to the last group under 'Section I'. The species belonging to the other section, or the taxonomically older species (having 5 stamens fertile) could not be examined as they occur in Malaysia. This lack of information is a great handicap in formulating any general theory on the phylogeny and origin of the genus on the basis of cytological data alone.

Although the present investigation suggests a stability in chromosome number in *Mangifera*, future observations, especially on the taxonomically older species (*M. Duperreana* Pierre, *M. pentandra* Hook f., and *M. lagenifera* Griff.) or other species of Section II, may show some lower chromosome number. The homogeneity in the range of floral structure in a majority of the species suggests, however, the possibility of the presence of the same chromosome number in most of them (Mukherjee, 1948a).

A study of the pollen morphology in 9 species of Section I and 4 species of Section II of the genus from herbarium specimens has shown that all of them have similar morphology and are of almost the same size (generally 23–32 μ) as in *M. indica* (Mukherjee, 1950). Size difference in pollen grains of related species can be a test for polyploidy in a genus, as has been found in *Quercus*, *Allium*, *Triticum*, *Euphorbia*, *Rosa* and *Tradescantia*, etc. (Cf. Cain, 1944; Darlington and Ammal, 1945). The similarity in shape and size of the pollen grains in species of *Mangifera* therefore

substantiates the expectation of finding a stable chromosome number (viz. $2n = 40$) in a majority of the species belonging to 'one fertile stamen' group.

Furthermore, it has been established (Hagerup, 1932) that species with varying chromosome numbers in a genus have evolved from the original type in those regions of the globe, which are characterized by an extremely low temperature (such as arctic region or mountain peaks), or high temperature and low humidity such as deserts (Wulf, 1943). All the species of *Mangifera* grow under almost similar climatic conditions, none occurring on mountain tops above 3,000 ft. or in the deserts (Mukherjee, 1949). They are distributed throughout Malaysian region in the tropics, the flora of which has never been subjected to great climatic changes during the geological periods since the origin of the angiosperms in the Cretaceous (Wulf, 1943). The stability in chromosome number, anticipated in majority of the species, is also indicated by the phyto-geographical distribution of the genus.

Morphological variations correlated with chromosome morphology.—The karyotype of a species, based on the morphology of its chromosome complement, is usually characteristic for it. A comparison of the karyotypes of component species of a genus shows differences, which may be marked or inconspicuous. A similarity in the phenotype between two species is more or less expressed by a similarity in their karyotypes (Babcock and Cameron, 1934). The chromosome morphology, therefore, becomes an important guide in tracing taxonomic affinity.

Whereas in *Zea mays*, *Vicia faba*, *Crepis* sp., *Scilla* sp., etc., some prominent chromosomes in their karyotypes, characteristic for each type, have been found, there are a large number of species, e.g. in *Salix*, etc. (Wilkinson, 1944), where no such distinct chromosome in the karyotype could be found.

A reference to the drawings of the somatic complements of *M. sylvatica* and the different varieties of *M. indica* emphasizes remarkable uniformity in size and morphology of the chromosomes. The differences between the complements are inconspicuous, and indeed are detectable beyond reasonable doubt only after a critical study. In spite of the lack of any prominent feature, certain chromosome types such as those with secondary constrictions, those without any apparent constriction, and those which are satellited appear to have some taxonomic importance. The chromosomes have therefore been differentiated into 11 types on the basis of their morphology. Four of these types (H-K) belong to the short length group, 4 (D-G) to the medium length and the other 3 (A-C) to the long group (see Idiogram with Table III). Some of the chromosomes of the medium group merges into similar chromosomes in the short length group, e.g. D with H, E with I, G with J. Hence out of 11 chromosome types enumerated above, 8 main types can be clearly distinguished.

The varieties of *M. indica* and the allied species *M. sylvatica* differ from one another mainly in the possession of different assortments of these 11 chromosome types; the total number of satellited and secondary constricted chromosomes varying between 9-16, and the unconstricted short chromosomes varying between 6-20 (cf. Table III).

The morphology of the varieties also shows that there is no marked divergence among any of them. They differ from one another firstly in the fruit characters, and secondly in the different colour ranges of the emerging leaves and panicle branches (Mukherjee, 1948b). The range of variation is continuous with gradual merging of characters intergrading from one extreme to the other. The continuous range in the phenotypic differentiation of the varieties is also manifest in their chromosome morphology, which shows minute differences among the varietal complements. No sharp differentiation is seen in any of the complements.

The chromosome morphology of *M. sylvatica* is very much similar to that of the morphologically allied *M. indica*. The geographical distribution of the two species are also overlapping. This correlation between the phenotype and karyotype supports the view of Babcock and Cameron, that taxonomically allied species and

varieties have similar chromosome morphology (cf. Sax, 1930; Goodspeed, 1934; Resende, 1937; Babcock, 1942; Meyer, 1944).

A comparison of the karyotypes brings out some interesting correlations between pairs of varieties. *Shadwalla* and *Bombai* (an important commercial type), which are morphologically very much allied, possess almost similar karyotypes except that *Bombai* has one pair of chromosomes with both SAT and secondary constriction. Such close inter-relationship is also found between *Kohitur* and *Panja Pasand*, *Alphonso* and *Daseri*, *Himsagar* and *Pairie*, *Anupam* and *M. sylvatica*.

The morphological classification of the varieties into 3 groups (i.e., *Round-*, *Ovate-oblong-*, and *Long-fruited*) on the basis of fruit character (Mukherjee, 1948b), does not indicate any significant correlation with the grouping of the varieties into 5 classes according to the maximum number (8, 10, 12, 14 or 16) of nucleolar chromosomes in the nucleus.

The occurrence in *Latra*, one of the round-fruited varieties, of a higher number (16) of satellited and secondary constricted chromosomes in its complement indicates that this group of varieties is of later origin. A significant justification for this view is obtained from the evidence that the *wild* mangoes of the present day belong to the *Ovate-oblong* group. Examination of other round-fruited varieties, e.g. *Rumani*, *Nazimpasand*, *Sabsang* and *Dudho*, will verify whether the above statement is correct or not.

Polyplloid Nature of the Mangoes.—Genetical and cytological studies have shown that from an evolutionary point of view, we can arrange our races of cultivated plants conveniently in the following four classes, according to their mode of origin (Crane, 1940):—

- (1) By selection from gene-mutation within a single species.
- (2) By simple autopolyploidy.
- (3) By selection from products of interspecific hybridization, unaccompanied by chromosome duplication or aberration;
- (4) By interspecific hybridization, accompanied by chromosome doubling (allopolyploidy) or other nuclear aberrations.

Investigation on the crops of temperate regions have shown that many of the cultivated species and races have originated by the last process (allopolyploidy) either in nature or under cultivation, e.g. *Dahlia variabilis*, *Prunus domestica* (European Plums), *Aesculus carnea*, *Rubus loganobaccus* (Crane, 1940). Amongst these, *Prunus domestica* is most interesting in view of the fact that the hypothesis of its origin in nature by hybridization between a diploid *Prunus divaricata* and a tetraploid *Prunus spinosa* followed by chromosome doubling, based on cytological and genetical observations (Crane and Lawrence, 1947) received confirmatory support from the investigations of Rybin (1936), who synthesized it from the above two species. Crane (1940) has also suggested that the tropical crops are likely to have originated along the same line.

Although no polyploid series of chromosome number has been found in the varieties of mango or in the allied species, the polyploid nature of the mangoes can be deduced from the following evidences:—

1. The diploid number, $2n = 40$, is itself sufficiently high to be the basic number for the genus and indicates its derivation from some plants with lower chromosome number through polyploidy.
2. Evidence for polyploidy is obtained from the presence of a high number (8–16) of satellited and secondary constricted chromosomes in the complement, which are nucleolar (Bhaduri, 1944; Bhaduri and Bose, 1947).

Since the establishment of De Mol's (1928) theory of numerical correlation between the number of nucleoli and the number of genomes present in a species,

suggesting the nucleolar number as an important guide to polyploidy, a large number of observations have accumulated (cf. Gates, 1942), on the basis of which Bhaduri came to the conclusion that higher nucleolar numbers have been evolved not through polyploidy alone, but hybridization and structural changes in chromosomes have also played an important rôle in the process (Bhaduri, 1942*a, b*; 1948). He further suggested that size difference in the nucleoli in a species is an important guide to its evolutionary history, and homomorphic pairs of nucleoli in the two poles of a dyad cell suggests the homozygous nature of the species and conversely heteromorphic pair suggests its heterozygous nature.

In addition to the above processes responsible for increase in nucleolar number, fragmentation of chromosomes at the regions of secondary constrictions has also been claimed recently (Bhaduri and Bose, 1947; Chakravorti, 1948) to play an important rôle in the process. Nucleolar number alone cannot therefore be used as a measure of the degree of polyploidy.

During the present investigation, *M. indica*, *M. sylvatica* and *M. caloneura* have been found to possess 8–16 nucleoli in a somatic cell, which are segregated into homomorphic pairs in the two nuclei within a dyad cell, suggesting their homozygous condition. Such a high number of nucleoli in the mangoes is due to their polyploid nature, and not due to segmental interchange or other structural changes in chromosomes, as evidenced by the striking regularity in pairing and disjunction of the bivalents during meiosis. It is worth pointing out here, that the large number of 'Prime types' found in *Datura stramonium* and *D. metel* each bearing the same chromosome number, $2n = 24$, and showing normal pairing and disjunction, differ from one another with respect to one or more interchange of segments of chromosomes (Bergner, Satina and Blakeslee, 1943; Blakeslee, *et al.*, 1940). This could only be detected by the formation of rings of four or more chromosomes during diakinesis in intervarietal crosses. It is difficult to state at the present stage whether such cytological differences exist between different varieties or species of *Mangifera*. It will therefore be an important line of investigation to examine cytologically the intervarietal crosses, which have already been produced at the Horticultural Research Stations in India and elsewhere.

3. During meiosis in the pollen-mother-cells the 40 chromosomes regularly pair into 20 bivalents in diakinesis, which separate ultimately into 20 homologous groups in anaphase. No multivalent formation or any other irregularity such as chromosome bridges or lagging chromosomes are seen. Such striking regularity in pairing and disjunction of chromosomes during meiosis indicates that the mangoes are not autopolyploids, but are allopolyploids. The good fertility in the varieties (the apparent sterility varying between 3–16%), further suggests that they may be amphidiploids.

Secondary association and Basic number.—A reference to Table IV shows that during meiotic metaphase, the 20 bivalents aggregate in groups of 4, 3, 2 or 1 to form a maximum secondary association into 8 units, indicating residual attraction between more distantly related chromosomes (Darlington and Moffet, 1930) and emphasizing the hybrid (allopolyploid) origin (Lawrence, 1931) of the mangoes. Recently Thomas and Revell (1946) have put forward the view that the characteristic secondary association between bivalents is due to the 'fusion between heterochromatic regions at pachytene' and gives 'little indication of homology'. Although 'secondary association shows no specificity' they, however, agree that 'there is a higher degree of association between the morphologically similar bivalents'. They moreover suggest that in the diploid, analysis of secondary association need not indicate chromosome relationship, whereas in the tetraploid it may do so, depending on '(a) the degree of prezygotene orientation, and (b) the amount and distribution of heterochromatin'. In the mangoes, the secondary association gives an additional evidence for their allopolyploid origin, and therefore is not in disagreement with the above view regarding secondary association in polyploids.

The maximum association of the bivalent groupings into 8 units indicates the basic number for the genus to be 8. Although no species with such low chromosome number is now known in *Mangifera* or any other genera of the family *Anacardiaceae*, future investigation may lead to the discovery of such a type. The occurrence of 8 distinct chromosome types in the complement of 40 is a significant corroboration for the view that 8 is the basic number (Nandi, 1936; Jacob, 1941).

The chromosome numbers, determined only in 4 genera of *Anacardiaceae*, show that 3 of them, *Rhus* (2 sp.), *Mangifera* (3 sp.) and *Semecarpus* (1 sp.), have respectively $2n = 30$, 40 and 60 chromosomes. The occurrence of 30 and 60 chromosome numbers in the allied genera suggests that they might have originated from a basic number of 5 or a multiple of 5; but *Mangifera* is indicated to have a basic number of 8. Whether there are two basic numbers in the family or that for *Mangifera* is a derived number can be determined definitely only by further observations.

Evolution of the varieties of mango.—Arguments put forward under previous headings have established beyond doubt the allopolyploid nature of the mangoes. Their amphidiploid origin is also strongly suggested by evidence from regular pairing and good fertility. It therefore appears that the primitive type or types, which subsequently gave rise to the mango varieties, originated through allopolyploidy and most probably amphidiploidy. The next problem is how so many varieties have originated?

The morphology of the innumerable varieties shows a gradual continuous change in their characters, intergrading in range, as is expected in a polyploid (Crane, 1940). Significantly the chromosome morphology also shows minute intergrading differences in the varietal complement. The phenotypic and the genotypic characters therefore show an interesting parallelism in the slow, intergrading continuous changes in their diagnostic features. In view of these cytological evidences it is suggested that differentiation of the varieties from the original type or types has primarily taken place through gene mutations. The selected type has been preserved under cultivation through vegetative propagation by grafting. The compatibility between the varieties being very close, due to the close similarity in their chromosome morphology, intervarietal hybridization, occurring freely in nature, further induces the production of new varieties. The huge diversity in mango varieties in India is also to be explained as due to their cultivation for a long period, thereby giving ample opportunity for hybridization and forces of selection to operate. The occurrence of a large number of variations in mangoes in India supports the observations of Vavilov (cf. Darlington and Ammal, 1945) that a cultivated or wild species is expected to show the greatest diversity in the 'mountain-and-valley regions nearest the equator' as has been found by him in the case of various crop plants. The area of the maximum range of diversity is possibly the centre of origin of the species.

SUMMARY.

The present investigation has shown that *Mangifera sylvatica*, *M. caloneura* and *M. indica* (including 23 cultivated varieties and 1 wild race) have the same chromosome number $2n = 40$ and $n = 20$. The presence of same chromosome number also in majority of the remaining species of *Mangifera*, is suggested by the evidence of similarity in the pollen size and morphology, observed in 13 species belonging to both the sections of the genus, as also by their phytogeographical distribution.

The total number of satellites and secondary constrictions in the complements of different species and varieties varies between 8–16 with the size of the chromosomes ranging from 0.4 to 2.0 μ . Another important characteristic is the presence of a large number of chromosomes without any apparent constriction in each complement. On the basis of their morphology the chromosomes have been distinguished into 11 types, of which 3 are intergrading and 8 distinct. An analysis of the karyotypes shows that the varieties of mango and the allied species differ from one another mainly in the possession of different assortments of these chromosome types, each complement showing slight intergrading difference without any sharp discontinuous change.

The phenotypic and the karyotypic characters show an interesting parallelism in the slow, intergrading continuous changes in their diagnostic features.

The number of nucleoli in a somatic cell varies between 8-16 and corresponds generally with the number of satellited and secondary constricted chromosomes. The varieties have been grouped into 5 classes according to the number of nucleolar chromosomes (8, 10, 12, 14 or 16). The morphological classification of varieties according to fruit-shape does not show any significant correlation with groupings according to nucleolar chromosome number.

A comparison of karyotypes, however, brings out some interesting correlations between pairs of varieties and species, viz. between *Shadwalla* and *Bombai*, *Kohitur* and *Panja Pasand*, *Alphonso* and *Duseri*, *Himsagar* and *Pairie*, and *Anupam* (*M. indica*) and *M. sylvatica*.

The nucleoli in each nucleus have definite size difference, viz. big, intermediate and small, and they form homomorphic pairs in the two nuclei in a dyad cell indicating the homozygous nature of the varieties.

Although no polyploid series of chromosome numbers has been found in the varieties of mango and in the allied species, their polyploid nature is indicated by the high number of somatic chromosomes and a correspondingly high number of nucleolar chromosomes.

A need for the examination of meiosis in intervarietal crosses has been stressed to find out if any segmental interchange of chromosomes has taken place as in *Datura*.

During meiosis, the chromosomes show a regular pairing into 20 bivalents and subsequent regular disjunction. No multivalent formation or any other peculiarity is seen. At metaphase, the bivalents show a maximum secondary association into 8 units. This phenomenon suggests 8 as the basic number for *Mangifera*. It is also supported by the presence of 8 distinct chromosome types. The presence of $2n = 30$ and 60 chromosomes in the allied genera *Rhus* and *Semecarpus* respectively suggests that there may be two basic numbers in *Anacardiaceae* or that 8 for *Mangifera* might have been derived from 5 or multiple of 5.

From the evidences put forward it appears that the primitive type or types, which subsequently gave rise to the mango varieties, originated through allopolyploidy, most probably through amphidiploidy. The differentiation of the numerous varieties then took place primarily through gene mutations, the selected type being preserved under cultivation by grafting. The compatibility between the varieties being very close, intervarietal hybridization has been perhaps another important factor in the production of new varieties. The huge diversity in the mangoes in India is also to be explained as due to their cultivation here for a long period, thereby giving ample opportunity for hybridization and forces of selection to operate.

ACKNOWLEDGMENT.

I express my gratitude to Prof. S. P. Agharkar, under whose supervision the work was conducted with financial assistance from the Indian Council of Agricultural Research. I acknowledge the valuable help and advice obtained from Dr. P. N. Bhaduri during the investigation and in preparing the manuscript. Thanks are also due to the Horticulturists, Bihar, Bengal and Madras, to the Superintendent, Royal Botanic Gardens, Calcutta, and to the officers of various Forest Departments for help in the collection of materials of cultivated and wild mangoes and the allied species.

BIBLIOGRAPHY.

- Babeck, E. B. and Cameron, D. R. (1934).—Chromosomes and phylogeny in *Crepis* II. The relationships of one hundred and eight species. *Univ. Calif. Publ. Agr. Sci.*, **6**: 287-324.
- Babeck, E. B. (1942). Systematics, Cytogenetics, and Evolution in *Crepis*. *Bot. Rev.*, **8**: 139-190.
- Bergner, A. D., Satina, S. and Blakeslee, A. F. (1943). Primo types in *Datura*. *Proc. Nat. Acad.*, **19**: 103-115.
- Bhaduri, P. N. (1942a). Application of new technique to cytogenetical re-investigation of the genus *Tradescantia*. *Journ. Genet.*, **44**: 87-127.
- (1942b). Cytological Analysis of Structural Hybridity in *Rhoeo discolor* Hance. *Journ. Genet.*, **44**: 73-85.
- (1944). Chromosome-nucleolus relationship and its bearing on cytogenetical interpretation. *Journ. Roy. Micr. Soc.*, **63**: 91-120.
- Bhaduri, P. N. and Bose, P. C. (1947). Cytogenetical Investigations in some common Cucurbits with special reference to Fragmentation of Chromosomes as a Physical basis of Speciation. *Journ. Genet.*, **48**: 237-256.
- Bhaduri, P. N. and Kar, A. K. (1948). Study of Chromosome Nucleolus Relationship and its bearing on the Interpretation of Oenothera Cytogenetics. *Bull. Bot. Soc., Bengal*, **2**: 1-14.
- Blakeslee, A. F. et al. (1940). Chromosome Investigations. Yearbook No. 39. *Carn. Inst. Wash. Dept. Genet.*, 203-211.

- Burns, W. and Prayag, S. H. (1921). The Book of the Mango. Bull. No. 103, Dept. Agric., Bombay.
- Cain, S. A. (1944). Foundations of Plant Geography, p. 428 (Harper and Bros., New York).
- Crane, M. B. (1940). The origin and behaviour of cultivated plants. The New Systematics (Clarendon Press, Oxford): 529-547.
- Crane, M. B. and Lawrence, W. J. C. (1947). The Genetics of Garden Plants, 3rd ed. (McMillan & Co., London).
- Chakravorti, A. K. (1948). Theory of Fragmentation of Chromosomes and Evolution of Species. *Sci. and Culture*, **13**: 309-312.
- Darlington, C. D. and Arnall, E. K. J. (1945). Chromosome Atlas of cultivated plants (George Allen and Unwin Ltd., London).
- Darlington, C. D. and Moffet, A. A. (1930). Primary and Secondary chromosome balance in *Pyrus*. *Jour. Genet.*, **22**: 129-151.
- Gates, R. R. (1942). Nucleoli and Related Nuclear Structures. *Bot. Rev.*, **8**: 337-409.
- Goodspeed, T. H. (1934). Nicotiana phylaxis in the light of chromosome number, morphology and behaviour. *Univ. Calif. Publ. Bot.*, **17**: 369-398.
- Hagerup, O. (1932). Über Polyploidie in Beziehung zu Klima, Ökologie, und phylogenie. *Hereditas*, **16**: 19-40.
- Jacob, K. T. (1941). Preliminary Observations on the Chromosome Morphology in Asiatic Cottons with special reference to their Phylogeny and Inter-relationships. *Trans. Bose Res. Inst., Calcutta*, **14**, 191-200.
- Lawrence, W. J. C. (1931). The Genetics and Cytology of *Dahlia variabilis*. *Journ. Genet.*, **24**: 257-306.
- Maheshwari, P. (1934). The Indian Mango. *Curr. Sci.*, **3**: 97-98.
- Meyer, J. R. (1944). Chromosome studies of Phlox. *Genetics*, **29**: 189-216.
- Mol, W. E. de (1928). Nucleolar number and size in diploid, triploid and aneuploid Hyacinths. *Cellule*, **38**: 7-64.
- Mukherjee, S. (1948a). Comparative Morphology of the species of *Mangifera* Linn. *Bull. Bot. Soc., Bengal*, **2**: 15-21.
- (1948b). The varieties of mango (*Mangifera indica* L.) and their classification. *Bull. Bot. Soc., Bengal*, **2**: 101-133.
- (1949). A Monograph on the genus *Mangifera* Linn. *Lloydia*, **12**: 73-136.
- (1950). Pollen analysis of some species of *Mangifera* in relation to Fruit-set and Taxonomy (in Press).
- Nandi, H. K. (1936). The chromosome morphology, secondary association and origin of cultivated rice. *Jour. Genet.*, **33**: 315-336.
- Resende, F. (1937). Über die Ubiquität der SAT—Chromosomen bei den Blütenpflanzen. *Planta*, **26**: 757-807.
- Roy, B. (1939). On the chromosome number of some cultivated varieties of mangoes (*Mangifera indica* L.). *Sci. and Culture*, **5**: 196.
- Rybin, V. A. (1936). Spontane und experimental erzeugte Bastarde zwischen schwarzdorn und Kirschlorberrbaum und das Abstammungsproblem der Kulturpflaume. *Planta*, **25**: 22-58.
- Sax, K. (1930). Chromosome stability in the genus *Rhododendron*. *Amer. Jour. Bot.*, **17**: 247-251.
- Sen, P. K. (1943). *Ann. Rep. Fruit Res. Sta., Bihar*, 1942-43.
- Sturrock, D. (1944). Notes on the Mango (published in co-operation of the Atkins Inst. of the Arnold Arboretum), 1-122.
- Thomas, P. T. and Revell, S. H. (1946). Secondary association and heterochromatic attraction. I. *Cicer arietinum*. *Ann. Bot., N.S.*, **10**: 159-164.
- Vavilov, N. I. (1926). Studies on the Origin of Cultivated Plants. *Bull. Appl. Bot., Leningrad*, **16**: 1-248.
- Wilkinson, J. (1944). The Cytology of *Salix* in relation to its Taxonomy. *Ann. Bot., N.S.*, **8**: 269-284.
- Wulf, E. V. (1943). An Introduction to Historical Plant Geography, 1-233 (Waltham, Mass., Chronica Botanica).

BAND SPECTRUM OF ZINC BROMIDE.

By C. RAMASASTRY and K. SREERAMAMURTY.

(Communicated by Dr. K. Rangadhama Rao, F.N.I.)

(Received November 4; read November 25, 1949.)

INTRODUCTION.

The band spectrum of the molecule of Zinc Bromide is the least known of the halides of Zinc. The only reported bands in the literature are those obtained by Walter and Barratt (1929) in absorption, 17 of them being measured from 3113Å to 3027Å. Howell (1943) examined these bands in the light of his argument that the spectra of Zinc halides, resulting from the excitation of the Zn 4s electron, should be due to a ${}^2\pi - {}^2\Sigma$ transition in which the ${}^2\pi$ separation is $2/3(4p, {}^3P, \text{Zn}) = 386 \text{ cm.}^{-1}$. Taking the two strongest of the Walter and Barratt absorption bands at $\lambda 3071$, $\nu 32553$ and $\lambda 3110$, $\nu 32145$ as the (0, 0) bands of the two component systems of the ${}^2\pi - {}^2\Sigma$ transition, he suggested a vibrational analysis.

Howell considered that the intensity distribution among the bands was in complete support of the proposed scheme and approximate values of ω' and ω'' were derived to be 250 and 220 units respectively, but an unexpected difficulty arose when the ZnI bands are considered. The magnitude of the lower state vibrational frequency, i.e., 220 cm.^{-1} is almost nearly equal to the corresponding well-established constant of the ZnI molecule. Howell was hence led to suspect the origin of the Walter and Barratt absorption bands and only tentatively assigned them to the ZnBr molecule indicating an obvious need for further work.

EXPERIMENTAL.

The authors investigated the spectrum of Zinc Bromide in emission under the conditions found suitable for the excitation of the other allied halides. Chemically pure Zinc Bromide is taken in a Pyrex discharge tube of simplified design (Ramasastry and K. R. Rao (1947); Ramasastry, 1948) and its characteristic spectrum is excited by a high frequency voltage (about 150v, 8Mc.) applied to the tube by means of external electrodes. As the molecule responsible for the Walter and Barratt's absorption bands was somewhat of a doubtful nature, the experiments are repeated with two samples of Zinc Bromide, one the post-war B.D.H. product and the other a prewar Merck supply. In both cases the spectra obtained were identical. Preliminary work with Hilger Medium quartz instrument showed that the entire spectrum from 2000Å to 6500Å consisted of only two groups of bands, one in the near ultraviolet round about 3000Å and the other in the visible. Due to the presence of many atomic lines of Zinc in the 3050Å region, the first group of bands are difficult to be identified at first glance as some of them appear line-like in the low dispersion. This difficulty is, however, got over to a large extent by giving a Zinc arc comparison also in juxtaposition with the ZnBr spectrum. Littrow quartz spectrograms brought out more clearly the existence of these bands.

Near Ultraviolet Bands of Zinc Bromide Systems C and D.

These emission bands are obtained for the first time in the present work. Table I contains the wavelength data. The absorption measurements of Walter

TABLE I.
Near Ultraviolet Bands of Zinc Bromide.

Band Head Data.				Assignment.				Remarks.
Walter and Barratt (Absorption).		Authors (Emission).		Authors.		Howell.		
$\lambda(\text{Int.})$	ν	$\lambda(\text{Int.})$	ν	System	Head type.	System	Head type.	
3113(1)	32114	3111.6(3)	32128	C(1, 1)	Q	C(0, 0)	P	
		3111.6(3)	32143	C(1, 1)	R			
3110(4)	32145	3108.9(5)	32157	C(0, 0)	Q	C(0, 0)	Q	
		3107.6(4)	32170	C(0, 0)	R			
3102(2)	32228	3102.3(1)	32224	D(0, 1)		C(1, 1)		
3093(1)	32322			D(2, 3)		C(2, 2)		
3085(1)	32405			D(4, 5)		C(3, 3)		
		3081.7(4)	32440	C(1, 0)				
		3075.8()	32502					Zn line also.
		3072.8(2)	32535	D(0, 0)	P			
3071(4)	32553	3072.0(5)	32542	D(0, 0)	Q	D(0, 0)		Violet degraded. Zn line also.
3068(3)	32585			D(1, 1)		D(1, 1)		
3064(2)	32628			D(2, 2)		D(2, 2)		
3060(1)	32670	3059.6 (0bd)	32675	D(3, 3)		D(3, 3)		
3056(0)	32713	3055.8(8d)	32715	C(2, 0) and D(4, 4)		D(4, 4)		
		3053.3(0)	32742					
3052(0)	32756	3051.7(0)	32760	D(5, 5)		D(5, 5)		
		3049.8(0)	32779(M)					
3048(0)	32799			D(6, 6)		D(0, 1)		
3044(0)	32842			D(7, 7)		D(1, 2)		
3039(0)	32896			D(1, 0)		D(2, 3)		
3035(0)	32939	3035.8(?)	32931	D(2, 1)		D(3, 4)		
		3034.8(1)	32942					
3031(00)	32963			D(3, 2)		D(4, 5)		
		3030.2(5)	32991	C(3, 0)				
		3027.9(0)	33017					
		3027.5(0)	33022					
3027(00)	33026	3027.0(0)	33027	D(4, 3)		D(5, 6)		Components.
		3023.1(1)	33069(M)	D(5, 4)				
		3018.3(?)	33122(M)					Masked by Zn line.
		3017.3(1)	33133(M)					
		3013.7(0)	33172					
		3013.2(1)	33177					Components.
		3012.9(1)	33180					
		3012.4(1)	33186					
		3005.0(2)	33268(M)	C(4, 0)				
		3002.1(1)	33300(M)					
		2997.8(1)	33348(M)					
		2989.9(2)	33436(M)					
		2983.8(1)	33505(M)					
		2982.4(1)	33520(M)					Isotopic heads ?
		2966.5(2)	33700(M)					

Note—Wavenumbers marked (M) are those measured only on the Medium Quartz Spectrograms.

and Barratt are also given in the same table. It could be seen that certain bands obtained in emission are not recorded in absorption and vice versa. In obtaining the vibrational analysis of these bands the following points of view are chiefly considered.

1. The assignment of the bands to the ZnBr molecule is supported by the authors' experimental results.

2. Examination of the relative values of the constants of Zinc halides shows that $\omega_e'' = 220$, derived by Howell for the lower state of ZnBr is certainly too small. The upper state constant $\omega_e' = 250$ is also out of step in the sequence of values of the constants of the corresponding states of the other Zinc halides (cf. Table II).

TABLE II.

Constants of the Band systems of Zinc Halides occurring near the 3P-1S Zn lines.

Molecule.	(0, 0) Band.	$\Delta\nu$	ω_e'	ω_e''	Reference.
ZnF	2677.0, 37344 2703.8, 36934	370	597 601	620 620	Rochester and Olsson (1939).
ZnCl	2942.2, 33978 2975.9, 33593	385	382 384	391 390	Cornell (1938).
ZnBr	3072.8, 32542 3108.9, 32157	386	~ 358 ~ 284	~ 318 ~ 312	Present work.*
	3071 , 32553 3110 , 32145	408	~ 250 ..	~ 220 ..	Howell (1943).
ZnI	3277.8, 30499 3318.1, 30129	370	~ 212 248	~ 220 223	Tiruvenganna Rao and K. R. Rao (1946). Howell (1943).

* From the new analysis given in the following pages.

3. The band system occurs in the region expected for the Zinc Bromide molecule and the electronic width of 408 cm.^{-1} deduced by Howell is of the correct order of magnitude.

4. The ground state vibrational frequency of ZnBr should lie between 390 of ZnCl and 223 of ZnI. This range could further be narrowed down (Ramasastry, 1949) as this constant should have a value intermediate between those of CuBr ($\omega_e'' = 314$) and GaBr ($\omega_e'' = 263$).

5. Two component systems of $2\pi-2\Sigma$ transition should occur and the main difficulty in the analysis is presumed to have arisen from the overlapping of the two component systems.

Strips (a) and (b) of Plate XIV are the enlargements of these bands from the Medium and Littrow Quartz spectrograms respectively. These consist of (1) a group of four headless bands in the 3110\AA region, (2) a definitely violet degraded band at 3072\AA with a weak P-head accompanying it, (3) a few other diffuse bands, some of these showed four components when seen under high magnification. Considering the band at $\lambda 3072$, $\nu 32542$ as the (0, 0) of one component system and the intense head at $\lambda 3108.9$, $\nu 32157$ of the 3110 group as the (0, 0) band of the other component system, the separation between the (0, 0) bands is obtained as 386 cm.^{-1} which agrees well with the predicted 2π width of 386 cm.^{-1} . On this basis, the four bands of the 3110 group are to be interpreted as R and Q heads of the (0, 0) and (1, 1) bands. This interpretation and the presence of a weak P-head accompanying the band at 3072\AA are consistent with the $2\pi-2\Sigma$ transition.

The diffuse bands, present on the plate, form into a regular progression with the (0, 0) band at 3108.8\AA , $\nu 32157$ as the first member. The vibrational scheme is shown in Table I. This component system of the ${}^2\pi-2\Sigma$ transition is designated as system C in conformity with the designations of the band systems of the other related molecules. The lower state frequency is about 312 cm.^{-1} which is of the correct order of magnitude. The component heads observed in the diffuse bands may be of isotopic origin.

System D.

The faint band at $\lambda 3102.3$, $\nu 32224$ may now be considered as the (1, 1) band of the second component system (hereafter referred to as system D), giving a lower state ω value of about 318 cm.^{-1} , with the (0, 0) band at $\lambda 3072.0$, $\nu 32542$. Thus this system consists of only these two bands in emission.

Intensity considerations, namely that one of the component systems of the ${}^2\pi-2\Sigma$ transition is poorly developed in the case of the other halides of Zn, Cd and Hg, also support this analysis. Further, the bands obtained by Walter and Barratt in absorption but not recorded in emission in the present work could also be fitted into the above analysis. The new classification of the Walter and Barratt absorption data is shown in Table I together with that of Howell.

Of the two components of the ${}^2\pi-2\Sigma$ transition, one is developed better in absorption and the other better in emission. The absorption and emission data are chiefly complementary; there are of course a few common bands. The vibrational constants for both the component systems and the ${}^2\pi$ electronic width are of the correct order of magnitude.

It has not been possible to include in the above analysis some of the diffuse bands occurring at the short wavelength end. It may be significant to note that about five bands starting with $\nu 33180$ are approximately equally spaced at intervals of about 83 cm.^{-1} and as, in all probability, these bands also belong to ZnBr, they may form another system altogether different from the two component band systems C and D of the ${}^2\pi-2\Sigma$ transition. There is need here for further investigation; particularly absorption pictures may prove to be of considerable help.

TABLE III.
Band Head data of Visible Bands of ZnBr.

Wavelength.	Int.	Wavenumber.	Wavelength.	Int.	Wavenumber.
4253.0	1	23506	3924.0	2	25477
30.0	1	23634	04.0	2	25608
04.0	1	23780			
			3885.5	2	25729
4181.5	1	23908	65.0	3	25866
60.5	1	24029	46.5	3	25990
40.0	1	24148	26.0	2	26130
17.5	1	24280	07.5	3	26257
4093.5	1	24422	3789.0	2	26385
70.5	1	24560	71.0	2	26511
49.0	1	24691	52.5	1	26641
28.0	2	24819	35.0	1	26766
06.0	2	24956	17.0	1	26896
3988.0	2	25068	3699.0	1	27027
66.0	2	25207	80.5	1	27163
45.5	2	25338	64.0	1	27264

The 'Visible' Bands.

The visible bands obtained in the present work extend from 4500\AA – 3600\AA . They are reproduced in strip (c). The direction of degradation is clearly towards the red but owing to the weak intensity of the bands and a general continuum covering them up, there is not much of contrast and consequently about 30 band heads only could be measured on the Hilger Medium Quartz and Fuess Glass spectrograms. The heads are not quite sharp excepting a few individual cases near 3850\AA and the measurements which may be correct to an Angstrom unit are given in Table III.

The band heads are located at approximately equal intervals of 130 cm^{-1} . Some of these bands showed partial resolution of rotational structure under the higher dispersion of the E_1 spectrograph. These 'visible bands' of ZnBr resemble, in their appearance, those of CdCl (Ramasastry, 1947), CdBr (Ramasastry, 1949) and ZnCl (from unpublished results of this laboratory), while the 'visible bands' of HgCl, HgBr, HgI, CdI, and ZnI have an altogether different appearance.

SUMMARY.

The characteristic emission band spectrum of Zinc Bromide molecule is recorded for the first time and it is found to consist of mainly two groups of bands, one in the near ultraviolet from 3110\AA to 2980\AA and the other in the visible. The near ultraviolet bands appear like diffuse lines and are analysed into two component systems, C and D, of a $2\pi-2\Sigma$ electronic transition with a 2π width of 386 cm^{-1} and the following vibrational constants:

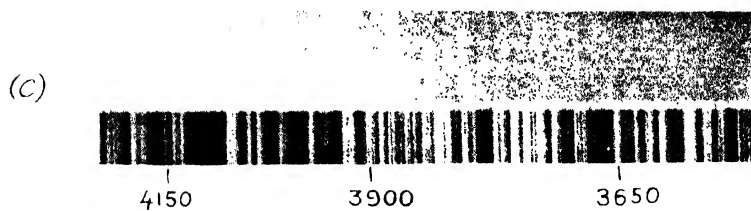
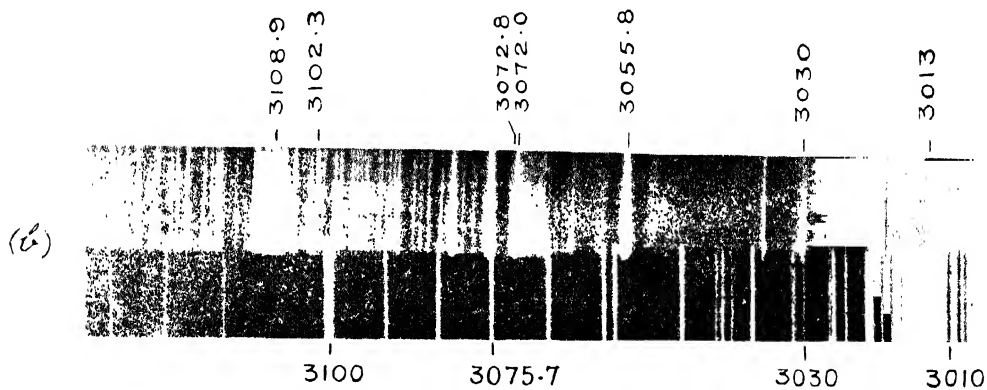
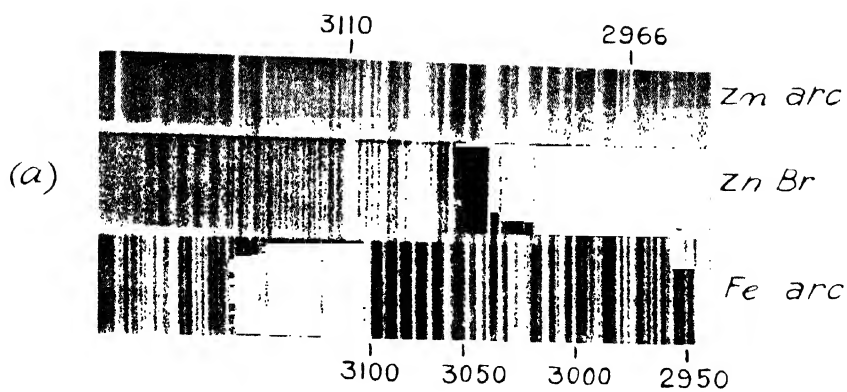
	(0, 0) band	ω_c''	ω_c'
System C	32157	~ 312	~ 280
System D	32542	~ 318	~ 350

The absorption data of Walter and Barratt could easily be fitted into the above analysis. The emission data (present work) and the absorption data (Walter and Barratt) are chiefly complimentary; there are of course a few common bands.

Measurements of about 30 red-degraded bands of ZnBr from 4500\AA to 3600\AA are also given and a recurring interval of 130 or 260 cm^{-1} is indicated.

REFERENCES.

- Cornell, S. D. (1938). Ultraviolet Band spectrum of HgCl, CdCl and ZnCl. *Phy. Rev.*, **54**, 341–346.
 Howell, H. G. (1943). The ultraviolet spectra and electron configuration of HgF and related halide molecules. *Proc. Roy. Soc.*, **A182**, 95–112.
 Ramasastry, C. (1947). The band spectrum of Cadmium Chloride. *Ind. J. Phys.*, **21**, 267–271.
 Ramasastry, C. and K. R. Rao (1947). Ultraviolet band systems of Mercury Iodide molecule—Part III. *Ibid.*, **21**, 143–152.
 Ramasastry, C. (1948). Ultraviolet bands of Zinc Iodide—Part III. *Ibid.*, **22**, 119–128.
 Ramasastry, C. (1949). Ultraviolet bands of Zinc Iodide molecule—Part III. *Ibid.*, **23**, 35–49.
 Ramasastry, C. (1949). Band spectrum of Cadmium Bromide. *Ibid.*—in print.
 Rochester, G. D. and Olsson, E. (1939). Das Bandenspektrum des MnF. *Zeits. f. Phys.*, **114**, 495–499.
 Tiruvenganna Rao, P. and Rao, K. R. (1946). Ultraviolet bands of Zinc Iodide—Part I. *Ind. J. Phys.*, **20**, 49–52.
 Walter and Barratt, S. (1929). The band spectra associated with Zinc, Cadmium and Mercury. *Proc. Roy. Soc.*, **A122**, 201–210.



NATIONAL INSTITUTE OF SCIENCES OF INDIA

Fifteenth Annual General Meeting

The Fifteenth Annual General Meeting of the National Institute of Sciences of India was held at 10 a.m., on Monday, the 2nd January, 1950, in the Amphitheatre of the Fergusson College, Poona.

The following Fellows were present:—

Prof. S. N. Bose, *President, in the Chair.*
Dr. D. R. Bhattacharya, *Additional Vice-President.*
Dr. J. N. Mukherjee, *Foreign Secretary.*
Prof. D. S. Kothari
Dr. H. S. Pruthi } *Secretaries.*

Prof. S. P. Agharkar.
Prof. S. L. Ajrekar.
Dr. J. B. Auden.
Prof. K. N. Bagechi.
Prof. K. Banerjee.
Dr. S. K. Banerji.
Mr. S. Basu.
Dr. P. N. Bhaduri.
Dr. S. K. Chakrabarty.
Dr. D. Chakravarti.
Dr. K. A. Chowdhury.
Dr. A. K. Das.
Prof. B. K. Das.
Dr. J. C. Ghosh.
Dr. R. N. Ghosh.
Prof. P. S. Gill.
Dr. B. C. Guha.
Dr. S. L. Hora.
Prof. A. C. Joshi.
Dr. M. S. Krishnan.
Prof. K. B. Madhava.
Prof. G. P. Majumdar.

Dr. K. Mitra.
Mr. G. C. Mitter.
Prof. P. C. Mitter.
Prof. M. A. Moghe.
Prof. Vishwa Nath.
Dr. B. P. Pal.
Dr. V. G. Panse.
Prof. G. R. Paranjpe.
Prof. C. Racine.
Dr. M. V. Radhakrishna Rao.
Dr. H. Srinivasa Rao.
Dr. B. Sundara Raj.
Dr. L. A. Ramdas.
Dr. J. N. Ray.
Prof. J. M. Sen.
Prof. T. R. Seshadri.
Dr. S. B. Setna.
Mr. V. V. Sohoni.
Dr. P. L. Srivastava.
Dr. P. V. Sukhatme.
Dr. R. S. Varma.
Dr. W. D. West.

Dr. N. A. Yajnik.

Besides, a large number of visitors were also present.

At the outset, the President referred to the death of Prof. Major Greenwood, an Honorary Fellow. A resolution of condolence was adopted, all standing.

The minutes of the Fifty-first Ordinary General Meeting, held on the 25th November, 1949, were read and confirmed.

The President announced that, as a result of scrutiny of voting papers received from Fellows, the following persons were duly elected Ordinary and Honorary Fellows of the Institute:—

Ordinary Fellows.

- (1) Dr. D. P. Antia, *Development Officer, Ministry of Industry and Supply, Government of India, New Delhi.*
- (2) Dr. F. C. Auluck, *Reader in Physics, University of Delhi, Delhi.*
- (3) Dr. P. L. Bhatnagar, *Head of the Department of Mathematics, St. Stephens College, and Reader in Mathematics, University of Delhi, Delhi.*
- (4) Dr. K. Biswas, *In-charge of duties of Director at the Herbarium, Royal Botanic Gardens, Sibpur, Howrah.*
- (5) Dr. J. P. Bose, *Officer-in-charge, Department of Biochemistry and Diabetes, School of Tropical Medicine, Calcutta.*
- (6) Dr. R. N. Chaudhuri, *Professor of Tropical Medicine, School of Tropical Medicine, Calcutta.*
- (7) Dr. V. M. Ghatage, *Assistant Professor of Aeronautical Engineering, Indian Institute of Science, Bangalore.*

- (8) Dr. H. Gupta, *Senior Lecturer in Mathematics, Government College, Hoshiarpur, E. Punjab.*
 (9) Dr. T. J. Job, *Chief Research Officer, Central Inland Fisheries Research Station, Manirampur, Barrackpore.*
 (10) Dr. R. S. Krishnan, *Professor of Physics, Indian Institute of Science, Bangalore.*
 (11) Dr. M. C. Nath, *Chitnavis Professor and Head of the Department of Biochemistry, University of Nagpur, Nagpur.*
 (12) Dr. H. N. Roy, *Research Officer (Protozoology), Indian Veterinary Research Institute, Mukteswar—Kumaon.*
 (13) Dr. M. R. Salui, *Superintending Geologist, Geological Survey of India, Calcutta.*
 (14) Dr. A. Sreenivasan, *Lecturer in Foods and Drugs, Department of Chemical Technology, University of Bombay, Bombay.*
 (15) Dr. R. S. Vasudeva, *Plant Pathologist, Indian Agricultural Research Institute, New Delhi.*

Honorary Fellows.

- (1) Dr. P. Debye, *Professor of Chemistry, Cornell University, Ithaca, New York, U.S.A.*
 (2) Dr. M. von Laue, *Professor of Theoretical Physics, University of Berlin, Germany.*
 (3) Dr. M. Siegbahn, *Professor of Physics, University of Uppsala, Sweden.*
 (4) Dr. E. Schrodinger, *Professor of Physics, Institute for Advanced Studies, Dublin, Eire.*

The President appointed Profs. S. P. Agharkar and K. N. Bagechi as scrutineers of the voting papers for the election of office bearers and Members of Council for the year 1950.

As a result of the scrutiny, the following were declared as duly elected to the Council:—

<i>President</i>	..	..	Prof. S. N. Bose (Calcutta).
<i>Vice-Presidents</i>	..	..	(1) Prof. A. C. Banerji (Allahabad).
		..	(2) Dr. K. S. Krishnan (Delhi).
<i>Treasurer</i>	..	..	Dr. C. G. Pandit (Delhi).
<i>Foreign Secretary</i>	..	..	Dr. J. N. Mukherjee (Delhi).
<i>Secretaries</i>	..	..	(1) Prof. D. S. Kothari (Delhi).
		..	(2) Dr. H. S. Pruthi (Delhi).
<i>Editor of Publications</i>	..	..	Dr. S. L. Hora (Calcutta).

Members of Council :

Dr. S. P. Agharkar (Poona).	Prof. R. C. Majumdar (Delhi).
Prof. K. N. Bahl (Lucknow).	Dr. H. R. Mehm (Allahabad).
Dr. S. K. Banerji (Delhi).	Mr. G. R. Paranjpe (Poona).
Mr. S. Basu (Poona).	Prof. P. Parija (Banaras).
Prof. S. R. Bose (Calcutta).	Dr. L. A. Ramdas (Poona).
Dr. B. C. Guha (Calcutta).	Mr. J. M. Sen (Calcutta).
Prof. A. C. Joshi (Hoshiarpur).	Prof. N. R. Sen (Calcutta).
Dr. S. Krishnan (Delra Dun).	Dr. P. V. Sukhatme (Delhi).
	Dr. A. C. Ukil (Calcutta).

The following Fellows were admitted under provisions of Rule 13:—

Dr. S. K. Chakrabarty.
 Dr. R. N. Ghosh.
 Dr. K. Mitra.
 Mr. G. C. Mitter.
 Prof. C. Racine.
 Dr. S. B. Setna.

The Secretaries presented the Report of the Council for the year 1949 (*vide* page 315).

The Report was adopted.

The President, Prof. S. N. Bose, then delivered a short address, *extempore*, the summary of which is as follows:—

He thanked the Fellows for his re-election for a second term. He gave a short review of the work of the Institute during the past year and laid stress on the

good work that the Institute was doing in distributing Fellowships to scholars attached to different research institutions. He was glad to note that the scheme of fostering research was bearing good fruit and that a number of interesting papers had already been published during the year by the scholars of the Institute which had been received favourably in the scientific world. He hoped that with more generous grants from Government, the Institute would be able to contribute substantially to the cause of scientific progress in India.

He remarked that the Institute had felt the need of a home of its own at its headquarters for some time, and he was glad to be able to report that the negotiations for the acquisition of land on lease were complete and a suitable grant for the construction of a building, had also been received from the Government. During the year under review, a number of Fellows of the Institute had attended different international congresses and conferences in various countries and he hoped that, in future, this would continue and more Fellows would be able to go abroad and thereby promote goodwill and co-operation in the scientific world. He was glad also to know that a number of scientists of eminence from abroad were attending the Science Congress and had come also as visitors at the Annual Meeting of the Institute. He extended to them a very cordial welcome and hoped that their visit and their presence would give enduring stimulus to scientific activity in the country.

In the absence of authors, the following papers were taken as read:—

- (1) *A critical Evaluation of the question of Cytoplasmic Inheritance in Yeasts* by M. K. Subramaniam. (Communicated by Dr. S. L. Hora.)
- (2) *The Embryo-sac of Fritillaria liliacea* by J. S. Agarwal. (Communicated by Prof. P. Maheshwari.)
- (3) *Luminescence Spectra of Alkalihalides* by H. N. Bose and J. Sharma. (Communicated by Prof. S. N. Bose.)
- (4) *The Development of the Vertical column in the Domestic Fowl* by Sivatosh Mookerjee. (Communicated by Dr. S. L. Hora.)
- (5) *Mallophaga infesting Birds in the Punjab* by M. Atiqur Rahman Ansari. (Communicated by Dr. H. S. Pruthi.)
- (6) *On the Determination of acoustic Influence by Curve Width Method* by R. G. Chatterji. (Communicated by Dr. R. N. Ghosh.)

(The papers after refereeing, if found suitable, would be published in the *Proceedings* of the Institute.)

Dr. S. B. Setna delivered the Chandrakala Hora Memorial Medal Lecture on *Growth of Fishery Industry: Side-lights on Fifteen years' work*.

The Symposium on *Operational Research in Peace and in War* organized by Prof. D. S. Kothari was then held. Prof. D. S. Kothari, Major-General Williams, Prof. K. B. Madhava, Dr. P. V. Sukhatme, Dr. R. S. Varma and Mr. Dilwali took part in the discussion.

ANNUAL REPORT, 1949

The Council of the National Institute of Sciences of India have the pleasure in submitting the following report on the general concerns of the Institute for the year 1949, under provisions of Rule 48(f).

Membership.

Out of 238 Ordinary Fellows at the close of the previous year, one died, two resigned, and the names of four (Dr. C. F. C. Beeson, Mr. C. C. Calder, Sir Arthur Olver, and Lt.-Col. J. A. Sinton) were struck off the list under Rule 36. Fifteen new Fellows were elected, but the election of one became null and void because of his failure to pay the admission fee within the period laid down in Rule 9. At the close of the year the number of Ordinary Fellows thus stood at 245 (Appendix I).

In addition to 24 Honorary Fellows listed in Appendix I, the following four were elected during the year:—

1. Dr. Louis de Broglie, Professor of Theoretical Physics, Poincaré Institute, Sorbonne, Paris, France.
2. Prof. Hans von Euler, Professor of Chemistry, Stockholm University, Stockholm, Sweden.
3. Dr. Harlow Shapley, Director of Harvard University Observatory and President, American Science Association, Cambridge, Mass., U.S.A.
4. Professor Georg Tischler, Botanical Institute, University of Kiel, Berlin, Germany.

Steps have been taken to confer on them the Honorary Fellowship of the Institute through diplomatic channels.

Meetings.

The Fourteenth Annual General Meeting was held in the Vizianagram Hall of the Allahabad University on 4th January, under the presidentship of Dr. S. S. Bhatnagar. His Presidential Address contained a résumé of developments in scientific research in the previous year.

There were five Ordinary General Meetings at which papers were read and discussed. The symposia organized were three:—

- | | | |
|-----------------------|----|--|
| January 4 (Allahabad) | .. | Stellar Constitution—organized by Prof. A. C. Banerji. |
| March 4 (Calcutta) | .. | Weights and Measures—organized by Prof. S. K. Mitra. |
| May 6 (Bangalore) | .. | The present position of research in Cytology, Genetics, and Plant Breeding in India—organized by Dr. S. P. Agharkar. |

The following lectures were also delivered at the Ordinary General Meetings:—

- | | | |
|-------------------|----|---|
| August 5 (Bombay) | .. | Smokeless Scientific Ovens for the Masses, by Dr. S. P. Raju. |
| October 6 (Delhi) | .. | Atomic Clocks, by Dr. K. S. Krishnan. |

The last-mentioned lecture was followed by the exposition of a technicolour film entitled 'Crystals go to War', which was obtained by the courtesy of Messrs. Toshniwal Bros., Ltd., of Bombay.

In addition, the following special lectures were delivered:—

- | | | |
|--------------------|----|---|
| January 14 (Delhi) | .. | Research Organization, by Sir Henry Tizard, Chairman, Advisory Council on Scientific Policy, Great Britain. |
|--------------------|----|---|

January 21 (Delhi)

.. Solar Magnetism, by Prof. Sydney Chapman, Sedleian Professor of Natural Philosophy in the University of Oxford.

Receptions were held in the Delhi University Hall to enable the Fellows of the Institute to meet Sir Henry Tizzard on 14th January, Professor Sydney Chapman on 21st January, Dr. G. B. Lal (Science Editor of Hearst Newspapers) on 4th February, and Delegates to the Defence Science Conference on 22nd April.

The Council.

The office-bearers and members elected at the Fourteenth Annual General Meeting together with representatives nominated by the Co-operating Academies, the Indian Science Congress Association and the Government of India constituted the Council for the year. They were:—

<i>President</i>	..	..	Prof. S. N. Bose (Calcutta).
<i>Vice-Presidents</i>	..	..	Prof. A. C. Banerji (Allahabad).
			Major-General S. S. Sokhey (Bombay).
<i>Additional Vice-Presidents</i>	..	..	Dr. D. R. Bhattacharya (Allahabad).
			Dr. K. S. Krishnan (Delhi).
			Dr. W. D. West (Calcutta).
			Representative of the Indian Academy of Sciences (nomination not received).
<i>Treasurer</i>	..	..	Dr. C. G. Pandit (Delhi).
<i>Foreign Secretary</i>	..	..	Dr. J. N. Mukherjee (Delhi).
<i>Secretaries</i>	..	..	Prof. D. S. Kothari (Delhi).
			Dr. H. S. Pruthi (Delhi).
<i>Editor of Publications</i>	..	..	Dr. S. L. Hora (Calcutta).
<i>Members</i>	..	..	Prof. K. N. Bagchi (Calcutta).
			Dr. S. K. Banerji (Delhi).
			Mr. S. Basu (Poona).
			Prof. H. J. Bhabha (Bombay).
			Prof. S. R. Bose (Calcutta).
			Dr. B. B. Dey (Madras).
			Prof. A. C. Joshi (Hoshiarpur).
			Dr. S. Krishna (Dohra Dun).
			Dr. K. S. Krishnan (Delhi).
			*Dr. H. R. Mehra (Allahabad).
			Prof. S. K. Mitra (Calcutta).
			Dr. B. Mukerji (Calcutta).
			Mr. G. R. Paranjpe (Poona).
			Dr. M. Prasad (Bombay).
			Prof. J. M. Sen (Calcutta).
			*Prof. N. R. Sen (Calcutta).
			Dr. A. C. Ukil (Calcutta).
<i>Ex-officio Members (Past Presidents)</i>			Dr. S. S. Bhatnagar (1947 and 1948) (Delhi).
			Dr. R. N. Chopra (1939 and 1940) (Jammu).
			Dr. J. C. Ghosh (1943 and 1944) (Delhi).
			Dr. Bainsi Prashad (1941 and 1942) (Delhi).
			Prof. M. N. Saha (1937 and 1938) (Calcutta).
			Dr. D. N. Wadia (1945 and 1946).
<i>Additional Members</i>	..	..	Dr. B. S. Guha (Calcutta).
			Prof. B. Sanjiva Rao (Bangalore).
			Dr. P. L. Srivastava (Allahabad).
			Representative of the Indian Academy of Sciences (nomination not received).
<i>Representative of Government of India.</i>			Dr. C. G. Pandit.

During the absence of Dr. S. L. Hora from India, Prof. J. M. Sen was appointed to act as Editor of Publications.

* Dr. H. R. Mehra and Prof. N. R. Sen were appointed by the Council to fill vacancies created by the election of Prof. A. C. Banerji as Vice-President and of Dr. C. G. Pandit as Treasurer.

The Sectional and other Committees appointed by the Council are shown in Appendix II. The Council held six meetings. Some important resolutions passed by the Council are given in Appendix III.

Rules of the Institute.

The Rules of the Institute were revised in the light of experience gained in the working of the Institute for the last thirteen years. The amended Rules will come into effect from 1st February, 1950.

Representations on Scientific Bodies.

Prof. A. C. Banerji, Prof. S. R. Bose, Prof. D. S. Kothari, Dr. M. S. Krishnan, and Dr. Baini Prashad represented the Institute on the Scientific Sub-Commission of the Indian National Commission set up for co-operation with UNESCO.

Dr. K. S. Krishnan, Prof. M. N. Saha, and Dr. D. N. Wadia were nominated to represent the Institute on the Central Board of Geophysics.

Prof. B. B. Dey and Prof. D. S. Kothari were nominated for the year ending 31st March, 1950, as representatives of the Institute on the Council of the Indian Association for the Cultivation of Science, Calcutta.

Dr. S. L. Hora, Prof. D. S. Kothari, Prof. Baini Prashad, and Prof. J. M. Sen were nominated to represent the Institute on the Committee constituted under the joint auspices of the Council of Scientific and Industrial Research and the National Institute of Sciences to draw up instructions for authors of scientific papers in the light of the recommendations of the Royal Society Scientific Information Conference.

The representatives on the Indian Standards Institution, of which the National Institute is a sustaining member, were as follows:—

<i>General Council</i> ..	..	Mr. G. R. Paranjpe.
<i>Chemical Division</i> ..	..	Dr. B. Mukerji (principal) and Prof. K. N. Bagchi (alternative).
<i>Weights and Measures Committee</i>		Prof. S. K. Mitra (principal) and Mr. G. C. Mitter (alternative).

Fresh representations were made to the Government of India to declare the National Institute as the body adhering on behalf of India to the International Council of Scientific Unions, pointing out that India's place should be rather with 32 scientifically advanced countries affiliated through national organizations corresponding to the National Institute than among the eight who have no National Academy or Institution to represent them, and that India cannot derive full benefit of her association with International Scientific Unions until corresponding National Committees are organized. The Government of India have intimated the Prime Minister's decision to the effect that for the present the procedure now followed, under which the initiative in dealing with International Scientific Unions rested with the Department of Scientific Research and the Department was advised at each stage by the National Institute, should be given a trial and the whole question could be reviewed at some later date when financial circumstances were more favourable.

Besides the International Council of Scientific Unions, India is now adhered to International Unions of Astronomy, Geodesy and Geophysics, Geography, Pure and Applied Physics, Chemistry, Radio Sciences, Biological Sciences, Crystallography and History of Science with their allied Associations and Commissions, and the question of joining the Union of Pure and Applied Mechanics is under consideration. The National Institute is consulted by the Government on all matters relating to India's adherence; it is kept in touch with the activities, of the

various unions by the Government and also by the Foreign Secretary who is, in his personal capacity, a member of the Executive Committee of the ICSU.

Delegations to International Conferences.

Fellows of the Institute represented the Government of India at various International Conferences during the year under report:—

1. United Nations Scientific Conference on the Conservation and Utilization of Resources, August-September (Lake Success, New York)—Dr. S. S. Bhatnagar (Leader), Dr. J. C. Ghosh, Dr. S. L. Hora, Dr. M. S. Krishnan, Prof. P. C. Mahalanobis, and Dr. J. N. Mukherjee. Dr. Bhatnagar also represented the National Institute.
2. United Nations Educational, Scientific and Cultural Organization—4th General Assembly, September-October (Paris)—Dr. J. C. Ghosh.
3. United Nations Educational, Scientific and Cultural Organization—Conference on problems of Nature Protection, August (Lake Success, New York)—Dr. S. L. Hora.
4. United Nations Educational, Scientific and Cultural Organization—Committee to examine problems of abstracting of literature in the field of Physics and related Sciences, December (Paris)—Dr. S. K. Banerji.
5. United Nations Statistical Commission, April-May (Geneva)—Prof. P. C. Mahalanobis.
6. United Nations Sub-Commission on Statistical Sampling, September (Geneva)—Prof. P. C. Mahalanobis.
7. International Council of Scientific Unions—General Assembly, September (Copenhagen)—Dr. J. C. Ghosh and Dr. J. N. Mukherjee.
8. Second International Congress of Crop Protection, July (London)—Dr. S. S. Bhatnagar.
9. International Organization for Standardization, June-July (Paris)—Dr. L. C. Verma.
10. Second International Biometric Conference, International Population Union, August-September (Geneva)—Prof. P. C. Mahalanobis.
11. Biennial Session of the International Statistical Institute, September (Berne)—Prof. P. C. Mahalanobis.
12. Canadian Mathematical Conference, August-September (Vancouver)—Prof. H. J. Bhabha.
13. Indo-Pacific Fisheries Council, March (Singapore)—Dr. Bains Prashad.
14. International Phyto-Sanitary Conference (Rubber) for South-East Asia, February (Singapore)—Dr. B. B. Mundkur.
15. International Phyto-Sanitary Conference for South-East Asia, April (Singapore)—Dr. H. S. Pruthi.
16. International Conference on Science Abstracting, June (Paris)—Dr. S. Bhagavantam.
17. International Biochemistry Conference, August (London)—Dr. B. B. Dikshit. Dr. B. C. Guha was elected Chairman of the Section on Vitamins.
18. Statistical Conference for South-East Asia (Singapore)—Dr. P. V. Sukhatme.
19. Fourth Empire Mining and Metallurgical Congress, July (Great Britain)—Dr. W. D. West.

Dr. S. Krishna, Dr. B. P. Pal and Mr. V. P. Sondhi were members of the Indian Scientific Delegation sent by the Government of India, at the invitation of the Australian Government, to visit important research centres in that country from 21st February to 4th April.

Institute's Building.

The Department of Scientific Research has kindly provided funds to pay the premium required by the Ministry of Works, Mines, and Power for the 3-acre plot allotted for the Institute Building, and a perpetual lease agreement has been signed. The ground rent for the first year also came from the same source, and a request has been made to increase correspondingly the recurring Government grant to the Institute.

It was originally intended to undertake, in the first instance, the construction of a main block comprising, on the ground floor, an Assembly Hall, an Entrance Hall, five Working Rooms, a Council Room, a Hall leading to the Council Room, and Library Rooms on the first floor. This was estimated to cost about Rs.4,00,000, while the Government grant at disposal was Rs.2,20,000. On the Ministry of Finance insisting upon the Institute restricting the initial construction to what could be done within the funds available to be complete with essential services, furniture, fittings, etc., it was decided to build for the time being the ground floor only *minus* the Council Room. Our architects in Bombay and the C.P.W.D. thought that the ground floor without the Council Room could be built and furnished within the Government grant, but quotations received from some leading Government contractors indicated that their charges would be nearer three lakhs than two lakhs, excluding the cost for essential services, furniture, fittings, etc. On account of the prevailing financial stringency the Government are not prepared to increase the grant for the time being, and the only alternative of simplification of designs and specifications is being resorted to. The architects are being pressed to give top priority to this job, and the Council hope that construction work would be undertaken early in New Year. The Council share the general regret that much time had been wasted over preliminaries.

Publications.

Eight numbers of Vol. XV of the *Proceedings*, about 420 pages, and three numbers (2, 3, and 4) of Vol. III of the *Transactions*, totalling 144 pp., were published during the year. The list of Contents and Index of Vol. XIV of the *Proceedings* was also distributed.

It is proposed to replace the *Indian Science Abstracts*, the publication of which has been under suspension since 1939 as a measure of paper economy, by a Report on the Progress of Science in India. The decade 1939-48 will be covered in one volume, and from 1949 it will be an annual publication.

Consolidated Report on the Working of Scientific Institutions.

At the instance of the Department of Scientific Research, a consolidated report on the working of scientific institutions—official and non-official—during 1947-48 was prepared for publication by the Ministry of Education.

Library.

About 400 books and pamphlets were added during the year. Twenty-four more Institutions agreed to exchange their publications with those of the Institute, which include:—

1. Royal Irish Academy.
2. Royal Society of Canada.
3. National Research Council of Egypt.
4. New York Academy of Sciences.
5. California Academy of Sciences.

A complete list of periodicals received is given in Appendix IV.

National Register of Scientific and Technical Personnel.

On completion of the compilation of materials received by the Institute, the work relating to the National Register, with all records, has been taken over by the Council of Scientific and Industrial Research.

Grant-in-aid of Publications.

It was decided to extend help to publications of learned societies to the aggregate of Rs.15,000 during the financial year 1949-50 as follows:—

	Rs.
1. Royal Asiatic Society of Bengal	500
2. National Academy of Sciences, India	1,000
3. Indian Science Congress Association	1,450
4. Indian Science News Association	1,000
5. Current Science Association	1,000
6. Indian Statistical Institute	500
7. Indian Mathematical Society	500
8. Calcutta Mathematical Society	500
9. Banaras Mathematical Society	300
10. Indian Physical Society	700
11. Indian Chemical Society	500
12. Society of Biological Chemists, India	300
13. Institution of Chemists (India)	600
14. Geological, Mining, and Metallurgical Society of India	300
15. Indian Ecological Society	200
16. Indian Botanical Society	700
17. Indian Society of Genetics and Plant Breeding	200
18. Entomological Society of India	500
19. Indian Institute for Medical Research	400
20. Indian Anthropological Institute	200
21. Indian Society of Agricultural Statistics	400
22. National Geographical Society of India	500
23. Physiological Society of India	200
24. Zoological Society of India	800
25. Indian Pharmaceutical Association	700
26. Indian Psychological Association	200
27. Indian Institute of Metals	400
28. Indian Dairy Science Association	250
29. Indian Phytopathological Society	200

The Department of Scientific Research of the Government of India was also approached to use their good offices for procuring printing paper of the required quality for publications of scientific societies.

Grants-in-aid to Learned Societies from the Central Government.

From among the Societies which approached the Institute for obtaining grants-in-aid from the Government funds, the following were recommended during the year:—

1. The Current Science Association, Bangalore.—A recurring grant of Rs.2,500 to enable the Association to convert 'Current Science' from a Monthly into a Fortnightly.
2. The Indian Physical Society, Calcutta.—A recurring grant of Rs.2,500 in support of the Society's journal converted from a Bi-monthly into a Monthly.
3. The Indian Science News Association, Calcutta.—A recurring annual grant of Rs.33,000 for three years; Rs.10,000 for improvements in 'Science and Culture' and Rs.20,000 for its Hindi edition; Rs.3,000 for bringing out special monographs.
4. The Indian Institute of Metals, New Delhi.—A recurring annual grant of Rs.3,000 in support of its 'Transactions'.

5. The Zoological Society of India.—A non-recurring grant of Rs.2,000 to maintain regular publication of its journal.
6. The Entomological Society of India.—A non-recurring grant of Rs.1,000 for bringing the publication of its journal to date.
7. The Mining, Geological, and Metallurgical Institute of India, Calcutta.—A non-recurring grant of Rs.5,000 for bringing arrears of publication to date.
8. The Physiological Society of India.—A non-recurring grant of Rs.1,000 in support of its journal converted from a Half-yearly into a Quarterly.

National Institute of Sciences of India Research Fellowships.

Of the four Senior Research Fellows remaining at the close of last year, Dr. P. N. Bhaduri (Botany) and Dr. K. Subba Rao (Chemistry) completed their respective terms, and Dr. S. D. Chatterjee (Physics) resigned after a year on obtaining a post-doctorate research fellowship of the National Research Council of Canada. Dr. A. P. Kapur (Zoology), who was selected against a vacancy arising in 1948 through the refusal of Dr. L. S. Ramaswami, joined on 27th April, and resigned with effect from 1st July, 1949, on being appointed at the Zoological Survey of India.

Out of 11 Junior Research Fellows at work in the beginning of the year, Dr. C. Datta (Botany) and Mr. P. A. R. Iyer (Zoology) completed their terms, Dr. N. K. Sarkar (Chemistry) resigned to proceed overseas and Mr. U. R. Burman and Dr. P. C. Mukharji were selected for award of Senior Research Fellowships.

Four Senior and seven Junior Research Fellowships were awarded during the year. One Senior Research Fellow resigned within three months and one Junior Fellow did not accept the offer. The vacancies were filled from the waiting list.

The following 10 Senior and 18 Junior Research Fellows were carrying on research at places mentioned against their names during the year:—

I. Senior Research Fellowships.

(a) Awarded in previous years—

1. Dr. P. N. Bhaduri (Botany). Calcutta University, Calcutta (up to February 19, 1949).
2. Dr. K. Subba Rao (Chemistry). Central College, Bangalore (up to July 24, 1949).
3. Dr. J. Bhimasonachar (Physics). Andhra University, Waltair.
4. Dr. S. Chatterjee (Physics). Bose Research Institute, Calcutta (up to September 1, 1949).
5. Dr. A. P. Kapur (Zoology). Zoological Survey of India (up to June 30, 1949).

(b) Awarded in 1949—

6. Mr. U. R. Burman (Mathematics). Calcutta University, Calcutta.
7. Dr. A. B. Kar (Physiology). Central Drugs Laboratory, Calcutta.
8. Dr. S. M. Mukhorji (Chemistry). Calcutta University, Calcutta (up to August 19, 1949).
9. Dr. K. V. Srinath (Botany). Central College, Bangalore.
10. Dr. P. C. Mukharji (Chemistry). Calcutta University, Calcutta (*vice* Dr. S. M. Mukhorji resigned).

II. Junior Research Fellowships.

Awarded in previous years—

1. Dr. C. Datta (Botany). Calcutta University, Calcutta (up to February 7, 1949).

2. Mr. P. A. R. Iyer (Zoology). Central College, Bangalore (up to January 31, 1949).
3. Dr. N. K. Sarkar (Chemistry). Calcutta University, Calcutta (up to February 28, 1949).
4. Mr. V. R. Thiruvengkatachar (Mathematics). Central College, Bangalore.
5. Mr. B. K. Banerjee (Physics). Calcutta University, Calcutta.
6. Mr. U. R. Burman (Mathematics). Calcutta University, Calcutta (up to May 16, 1949).
7. Mr. K. Das Gupta (Physics). Calcutta University, Calcutta.
8. Mr. S. D. Misra (Zoology). Lucknow University, Lucknow.
9. Dr. P. C. Mukharji (Chemistry). Calcutta University, Calcutta (up to October 16, 1949).
10. Mr. S. Veda Raman (Chemistry). Indian Institute of Science, Bangalore.
11. Mr. Y. Sunder Rao (Botany). Government College, Hoshiarpur.
12. Dr. P. N. Agarwal (Chemistry). National Chemical Laboratory, Poona (*vice* Mr. T. M. Mahadevan (Geology) who did not accept the offer).
13. Miss Ira Bose (Zoology). Calcutta University, Calcutta.
14. Mr. S. Datta Majumdar (Physics). Calcutta University, Calcutta.
15. Dr. S. G. Joshi (Chemistry). Maharashtra Association for the Cultivation of Science, Poona.
16. Mr. D. K. Mukherji (Botany). Indian Agricultural Research Institute, New Delhi.
17. Mr. K. Subramanyam (Botany). Central College, Bangalore.
18. Mr. B. V. Sukhatme (Mathematics). Indian Council of Agricultural Research, New Delhi.

Imperial Chemical Industries (India) Research Fellowships.

Of the seven ICI Research Fellows remaining at the close of previous year, Dr. R. G. Chatterjee (Chemistry) resigned before the expiry of his term on getting an appointment in the Bengal Educational Service. Seven fresh awards were made during the year, three of which were to fill vacancies arising from resignation or non-acceptance.

The following 14 ICI Fellows were carrying on research at places mentioned against their names during 1949 :—

(a) *Awarded in previous years—*

1. Mr. S. P. Basu (Biology-Zoology). Zoological Survey of India, Calcutta.
2. Mr. H. N. Bose (Physics). Calcutta University, Calcutta.
3. Dr. R. G. Chatterjee (Chemistry). Calcutta University, Calcutta (up to July 1, 1949).
4. Mr. T. V. Desikachary (Biology-Botany). Madras University, Madras.
5. Mr. J. Mitra (Biology-Botany). Calcutta University, Calcutta.
6. Mr. T. V. R. Pillay (Biology-Zoology). Zoological Survey of India, Calcutta.
7. Dr. C. V. Subramanian (Biology-Botany). Madras University, Madras.

(b) *Awarded in 1949—*

8. Dr. S. N. Ghosh (Physics). Calcutta University, Calcutta.
9. Dr. L. R. Row (Chemistry). Andhra University, Waltair.

10. Dr. A. K. Chakravarti (Biology-Botany). Calcutta University, Calcutta.
11. Dr. A. P. Mahadevan (Chemistry). University of Madras, Madras (up to October 22, 1949).
12. Dr. C. Ramasastry (Physics). Andhra University, Waltair.
13. Dr. K. K. Reddi (Chemistry). Indian Institute of Science, Bangalore.
14. Mr. P. K. Sen Chaudhury (Physics). Bose Research Institute, Calcutta.

Chandrakala Hora Memorial Medal.

The first award of the medal was made to Dr. S. B. Setna, Director of Fisheries, Bombay, for making conspicuously important contributions to the development of fisheries in India during the preceding five years.

Financial.

The recurring Government grant-in-aid towards expenditure on salaries of staff, research fellowships, travelling, library and publications amounted to Rs.1,57,000 during the financial year 1948-49. The Calcutta University, as in previous years, donated a sum of Rs.500 in aid of the Institute.

The audited accounts for the financial year ending 31st March, 1949, are given in Appendix V, in which are also given subsidiary statements relating to the ICI Research Fellowships grant, Chandrakala Hora Memorial Medal Endowment, the grant for compilation of a National Register of Scientific and Technical Personnel and the Popularization of Science Fund.

The Revised Estimates for 1949-50 and the Budget Estimates for 1950-51 are shown in Appendix VI.

Summaries of Annual and Final Reports of Research Fellows are given in Appendix VII.

APPENDIX I

LIST OF FELLOWS

ORDINARY FELLOWS

1. ABRAHAM, W. E. V., Lt.-Col., A.R.C.S. (I.), F.G.S., M.Inst.P.T., Managing Director, Burmah Oil Co., Ltd., Britannic House, Finsbury Circus, London, E.C. 2. (1936).
2. AGHARKAR, S. P., M.A., Ph.D., F.L.S., Head of the Dept. of Botany, Maharashtra Association for the Cultivation of Science, Law College, Poona 4.
3. AHMAD, BASHIR, M.Sc., Ph.D., Director, Institute of Chemistry, Punjab University, The Mall, Lahore. (1944).
4. AHMAD, NAZIR, O.B.E., M.Sc., Ph.D., Secretary, Pakistan Development Board, Block No. 44, Pakistan Central Secretariat, Karachi.
5. AIYAR, R. GOPALA, M.A., L.T., M.Sc., Professor of Zoology, Andhra University, Waltair. (1938).
6. AJREKAR, S. L., B.A. (Cantab.), Dip. Agric., I.E.S. (Retired), 855 Shivajinagar, Bhandarkar Institute Road, Poona 4.
7. ANANDA RAU, K., Rao Bahadur, M.A., I.E.S. (Retd.), 29 Bong Road, Thyagarayanagar, Madras.
8. ASH, W. C., B.Sc., M.Inst.C.E., A.M.I.Mech.E., c/o Lloyds Bank Ltd., 6 Pall Mall, London.
9. AUDEN, J. B., M.A., Sc.D. (Cantab.), Superintending Geologist, Geological Survey of India, 27 Chowringhee Road, Calcutta. (1938).
10. AWATI, P. R., B.A. (Cantab.), D.I.C., I.E.S. (Retd.), 759/20 Deccan Gymkhana, Poona 4.
11. BAGCHEE, K. D., D.Sc., D.I.C., Forest Botanist, Forest Research Institute, New Forest, Dehra Dun.
12. BAGCHI, K. N., Rai Bahadur, B.Sc., M.B., D.T.M., F.R.I.C., 5 Ballygunge Place, Ballygunge, Calcutta 19. (1940).
13. BAUL, K. N., D.Sc., D.Phil., F.R.A.S.B., Professor of Zoology, Lucknow University, Lucknow.
14. BANERJEE, K., D.Sc., Mahendralal Sircar Professor of Physics, Indian Association for the Cultivation of Science, 210 Bowbazar Street, Calcutta 12. (1939).
15. BANERJI, A. C., M.Sc., M.A., F.R.A.S., I.E.S., Professor of Mathematics, Allahabad University; Gyan Kutir, Boli Road, Allahabad.
16. BANERJI, I., D.Sc., Lecturer in Botany, Calcutta University, 35 Ballygunge Circular Road, Calcutta 19. (1945).
17. BANERJI, S. K., O.B.E., D.Sc., Director-General of Observatories, India (retd.), 3, Ramani Chatterji Road, P.O. Rashbehari Avenue Calcutta.
18. BARDHAN, J. C., D.Sc. (Cal. & Lond.), Khaira Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta 9. (1942).
19. BASU, J. K., M.Sc., Ph.D. (Lond.), Soil Physicist to the Government of Bombay, Central Buildings, Poona. (1941).
20. BASU, N. M., M.A., 63 Hindusthan Park, Ballygunge, Calcutta. (1944).
21. BASU, S., M.Sc., Dy. Director-General of Observatories, Meteorological Office, Ganesh Khind Road, Poona 5. (1946).
22. BASU, U. P., D.Sc., Director, Bengal Immunity Research Institute; 98/4 Surendranath Banerjee Road, Calcutta 14. (1946).
23. BEHARI, RAM, M.A., Ph.D., Sc.D. Professor of Mathematics, Delhi University, Delhi. (1941).
24. BHABHA, H. J., Ph.D., D.Sc. (Hon.), F.R.S., Director, Tata Institute of Fundamental Research, Apollo Pier Road, Bombay. (1941).
25. BHADURI, J. L., D.Sc. (Edin.), Lecturer in Zoology, Calcutta University, 35 Ballygunge Circular Road, Calcutta 19. (1949).
26. BHADURI, P. N., Ph.D., F.R.M.S., F.R.H.S., F.L.S., Assistant Cytogeneticist, Indian Agricultural Research Institute, Pusa Road, New Delhi. (1944).

27. BHAGAVANTAM, S., D.Sc., Professor of Physics, Andhra University, Waltair. (1949).
28. BHARADWAJ, Y., M.Sc., Ph.D. (Lond.), F.L.S., Principal, Jaswant College, Jodhpur. (1937).
29. BHARUCHA, F. R., M.Sc., D.Sc., Professor and Head of the Department of Botany, Royal Institute of Science, 6 Alexander Road, New Gamdevi, Bombay. (1939).
30. BHASKARA SHASTRI, T. P., Rao Saheb, M.A., F.R.A.S., Director, Nizamiah Observatory (Retired); 'Manorama', Begumpet, Hyderabad (Deccan).
31. BHATTNAGAR, SIR S. S., Kt., O.B.E., D.Sc., F.R.S., F.R.I.C., F.Inst.P., Secretary, Department of Scientific Research, Government of India, Central Secretariat, North Block, New Delhi.
32. BHATTACHARYA, D. R., Rai Bahadur, D.Sc., Ph.D., F.Z.S., Vice-Chancellor, Allahabad University; 7 Malaviya Road, Allahabad.
33. BHIMACHAR, B. S., D.Sc., Fishery Biologist, Central Marine Fisheries Research Station, West Hill, Calicut. (1948).
34. BOMFORD, G., Brigadier, R.E., Hainton Lodge, Sutton Courtenay, Berkshire, England. (1935).
35. BOR, N. L., C.I.E., M.A., D.Sc., F.L.S., c/o Messrs. Lloyds Bank, Ltd., 6 Pall Mall, London, S.W. 2. (1941).
36. BOSE, D. M., M.A., B.Sc., Ph.D., Director, Bose Institute, 92/3 Upper Circular Road, Calcutta 9.
37. BOSE, G. S., D.Sc., M.B., Professor and Head of the Department of Psychology, Calcutta University, 92 Upper Circular Road, Calcutta 9.
38. BOSE, N. K., M.Sc., Ph.D., Director, River Research Institute, Bengal, Anderson House, Alipur, Calcutta. (1938).
39. BOSE, P. C., B.Sc. (Glas.), Deputy Director, Health Services (Engineering), Government of West Bengal; 21 Mandeville Gardens, Calcutta. (1948).
40. BOSE, P. K., D.Sc., Director, Indian Lac Research Institute, Namkum, Ranchi. (1944).
41. BOSE, R. C., M.A., Professor, Institute of Mathematical Statistics, University of N. Carolina, Chapel Hill, N.C., U.S.A. (1942).
42. BOSE, S. N., M.Sc., Khaira Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta 9.
43. BOSE, S. R., M.A., D.Sc., F.R.S.E., Professor of Botany, R. G. Kar Medical College, 1 Belgachia Road, Calcutta. (1935).
44. BURRIDGE, W., D.M., M.A. (Oxon.), 366 Wood Stock Road, Oxford.
45. CHAKRABARTY, S. K., D.Sc., Head of the Department of Mathematics, Bengal Engineering College, Botanic Gardens P.O., Howrah. (1949).
46. CHAKRAVARTI, D., D.Sc., Lecturer in Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta 9. (1949).
47. CHATTERJEE, N. C., Rai Bahadur, D.Sc., A.I.I.Sc., 18 Rajpur Road, Dehra Dun. (1942).
48. CHATTERJEE, S. C., D.Sc., Head of the Department of Geography, Patna College, Bankipore, Patna. (1948).
49. CHOPRA, B. N., D.Sc., F.L.S., Deputy Fisheries Development Adviser, Government of India, Ministry of Agriculture, New Delhi. (1935).
50. CHOPRA, SIR R. N., Kt., C.I.E., M.D., Sc.D., F.R.A.S.B., F.R.C.P., Brevet-Col., I.M.S. (Retired), Director, Drug Research Laboratory, Jammu-Tawi, Jammu and Kashmir State.
51. CHOWDHURY, J. K., M.Sc., Dr.Phil. (Berlin), Head of the Department of Chemistry, Bose Institute, 93 Upper Circular Road, Calcutta 9. (1938).
52. CHOWDHURY, K. AHMAD, M.B.E., B.A., B.Sc., M.S., D.Sc., Wood Technologist, Forest Research Institute, New Forest, Dehra Dun. (1940).
53. CHOWLA, S., M.A., Ph.D., School of Mathematics, Institute of Advanced Study, Princeton, New Jersey (U.S.A.).
54. COATES, J., A.R.S.M., F.G.S., Eyton House, Leominster, Herefordshire, England. (1946).
55. CROOKSHANK, H., C.I.E., B.A., B.A.I., D.Sc., Geological Survey of Pakistan, Quetta. (1938).
56. DAS, A. K., D.Sc., Director, Solar Physics Observatory, Kodaikanal, S. India. (1943).
57. DAS, B. K., D.Sc. (Lond.), Professor and Head of the Department of Zoology, Osmania University; c/o Raghe Ali's House, 151 Morredpally, Secunderabad, Deccan. (1949).
58. DASTUR, J. F., M.Sc., D.I.C., Scarsdale, Panday Road, Colaba, Bombay. (1948).

59. DASTUR, R. H., M.Sc., Plant Physiologist, Institute of Plant Industry, Indore.
60. DATTA, S., D.Sc., D.I.C., Director of Public Instruction, Bengal; 39 Hindusthan Park, P.O. R.B. Avenue, Calcutta. (1935).
61. DATTA, S., D.Sc., F.R.S.E., M.R.C.V.S., D.T.V.M., Major, Director, Indian Veterinary Research Institute, Izatnagar, Bareilly, U.P. (1938).
62. DE, M. N., M.B. (Cal.), M.R.C.P. (Lond.), 32 Ganesh Chandra Avenue, Calcutta. (1942).
63. DE, P., M.B. (Cal.), F.R.C.P.E., 172 Lansdowne Road, Calcutta 29. (1943).
64. DESAI, R. D., D.Sc. (Lond.), D.I.C., F.R.I.C., Department of Chemical Technology, Bombay University, Matunga Road, Bombay. (1942).
65. DEY, B. B., D.Sc., F.R.I.C., I.E.S. (retd.), 77 High Road, San Thome, Madras.
66. DHAR, N. R., D.Sc., F.R.I.C., I.E.S., Professor of Chemistry, Allahabad University, Allahabad.
67. DIKSHIT, B. B., M.B.B.S. (Bombay), Ph.D. (Edin.), M.R.C.P. (Edin.), D.P.H. (Calcutta), Principal, B.J. Medical College, Poona. (1941).
68. DUTT, S. B., D.Sc., D.I.C., F.R.I.C., Professor of Chemistry, Delhi University, Delhi. (1935).
69. DUTTA, A. K., D.Sc., Physics Department, University College of Science, 92 Upper Circular Road, Calcutta 9. (1948).
70. DUTTA ROY, R. K., Dr. Ing., Chemist, Geological Survey of India, 27 Chowringhee Road, Calcutta 13. (1948).
71. ELWIN, VERRIER, M.A., D.Sc. (Oxon.), F.R.A.S.B., Taru House, P.O. Patangarh, Dt. Mundla, C.P. (1943).
72. EVANS, P., B.A., F.G.S., Chief Geologist, Burmah Oil Co., Ltd., Britannic House, Finsbury Circus, London, E.C. 2.
73. FERMOR, SIR LEWIS, LL. Kt., O.B.E., D.Sc., A.R.S.M., M.Inst.M.M., F.G.S., F.R.A.S.B., F.R.S., 24 Durdham Park, Bristol 6.
74. FOWLER, GILBERT J., D.Sc., F.R.I.C., Consulting Chemist, Central Hotel, Bangalore.
75. FOX, SIR CYRIL S., Kt., D.Sc., M.I.Min.E., F.G.S., F.R.A.S.B., Tudor House, 19 Queensmoro Road, Wimbledon, London, S.W. 19.
76. GANAPATHI, K., D.Sc., Assistant Director, Chemotherapy Department, Haffkine Institute, Parel, Bombay. (1946).
77. GANGULY, P. B., D.Sc. (Lond.), Principal, Science College, Patna. (1945).
78. GEE, E. R., M.A., F.G.S., Waveney, The Linkway, Sutton, Surrey, England. (1935).
79. GHOSH, R. N., D.Sc. (Lond.), Reader in Physical Chemistry, University College of Science, 92 Upper Circular Road, Calcutta 9. (1942).
80. GHOSH, J., M.A., Ph.D., Principal, Presidency College; 9 Satyen Datta Road, Calcutta 29. (1936).
81. GHOSH, SIR J. C., Kt., D.Sc., Director-General of Industries and Supplies, Shahjahan Road, New Delhi.
82. GHOSH, P. K., M.Sc., D.I.C., D.Sc. (Lond.), Geologist, Geological Survey of India, 27 Chowringhee Road, Calcutta 13. (1941).
83. GHOSH, R. N., D.Sc., Reader in Physics, Allahabad University; 152 South Malaka, Allahabad. (1939).
84. GHOSH, SUDHAMOY, M.B.E., D.Sc. (Edin.), F.R.I.C., Emeritus Professor, School of Tropical Medicine; 15 Justice Chundernabad Road, P.O. Elgin Road, Calcutta. (1945).
85. GHURYE, G. S., M.A., Ph.D., Professor of Sociology, University of Bombay, Fuller Road, Bombay. (1941).
86. GILL, P. S., M.S., Ph.D. (Chicago), F.A.P.S., Dean, Faculty of Science, Muslim University, Aligarh. (1945).
87. GLENNIE, E. A., D.S.O., Brigadier, R.E., Steepways, Cross Oak Road, Berkhamsted, Herts, England.
88. GRAVELY, F. H., D.Sc., F.R.A.S.B., 52 London Road, Reading, England.
89. GUHA, B. C., D.Sc., Damodar Valley Corporation, Anderson House, Alipore, Calcutta 27. (1941).
90. GUHA, B. S., M.A., A.M., Ph.D., F.R.A.S.B., Director, Department of Anthropology, Indian Museum, 27 Chowringhee Road, Calcutta.
91. GUHA, P. C., D.Sc., Professor of Organic Chemistry, Indian Institute of Science, Malleswaram, Bangalore. (1935).

92. GUPTA, J. C., M.B. (Cal.), Professor of Pharmacology and Officer-in-charge, Indigenous Drugs Inquiry (I.R.F.A.), School of Tropical Medicine and Medical College, Calcutta. (1945).
93. HADDOW, J. R., O.B.E., M.R.C.V.S., D.V.S.M., I.V.S., Senior Research Officer, Foot and Mouth Disease Research Station, Pirbright, Near Woking, Surrey, England.
94. HEILIG, Robert, M.D., Chief Physician, Jaipur, Rajputana. (1948).
95. HERON, A. M., D.Sc., F.G.S., F.R.G.S., F.R.S.E., F.R.A.S.B., Geological Survey of Pakistan, Quetta.
96. HORA, S. L., Rai Bahadur, D.Sc., F.R.S.E., F.Z.S., F.R.A.S.B., Director, Zoological Survey of India, Jabakusum House, 34 Chittaranjan Avenue, Calcutta 12.
97. HUSAIN, M. AFZAL, Khan Bahadur, M.A., M.Sc., I.A.S., Chairman, Pakistan Public Service Commission, Karachi.
98. ISHAQ, MOHAMMED, M.Sc., Ph.D., D.I.C., 21 Cooper Road, Lahore. (1940).
99. IYENGAR, M. O. P., M.A., Ph.D., F.L.S., University Professor of Botany, Madras University (Retired); 71 Venkatarangam Pillai Street, Triplicane, Madras.
100. JACOB, K., D.Sc., Palaeobotanist, Geological Survey of India, 27 Chowringhee Road, Calcutta 13. (1949).
101. JOSHI, A. C., D.Sc., Professor of Botany, Government College, Hoshiarpur. (1938).
102. JOSHI, S. S., D.Sc. (Lond.), Principal, College of Science and Head of the Department of Chemistry, Banaras Hindu University, Banaras. (1945).
103. KADAM, B. S., Ph.D., Director, Central Tobacco Research Institute, Rajahmundry, M. & S.M. Ry. (1946).
104. KAPUR, S. N., Ph.D., Officer-in-charge, Wood Working and Timber Mechanics Branch, Forest Research Institute, 22 Old Survey Road, Dehra Dun.
105. KHAN, HAMID, M.Sc., LL.B., Ph.D., Reader and Head of Zoology Teaching, Punjab University, Lahore. (1944).
106. KHANOLKAR, V. R., M.D., Director of Laboratories and Research, Tata Memorial Hospital, Hospital Avenue, Parel, Bombay. (1946).
107. KHAUSTGIR, S. R., Ph.D., D.Sc., F.R.S.E., Department of Physics, Banaras Hindu University, Banaras. (1944).
108. KICHLU, P. K., D.Sc., Professor of Physics, Delhi University, Delhi. (1935).
109. KINI, M. G., M.B.B.S., M.Ch. (Orth.), F.R.C.S., Captain, M.C., 3rd Floor, Connaught Mansion, Colaba, Bombay 5. (1944).
110. KOSAMBI, D. D., S.B. (Harvard), Professor of Mathematics, Tata Institute of Fundamental Research, Apollo Pier Road, Bombay 1. (1946).
111. KOTHARI, D. S., M.Sc., Ph.D., Scientific Adviser, Ministry of Defence, Government of India; 5 University Road, Delhi. (1936).
112. KRISHNA, S., C.I.E., Ph.D., D.Sc., Director of Forest Research, Forest Research Institute, New Forest, Dehra Dun.
113. KRISHNAN, SIR K. S., Kt., D.Sc., F.R.S., Director, National Physical Laboratory, New Pusa Institute, New Delhi.
114. KRISHNAN, K. V., M.B.B.S., L.R.C.P., D.B., D.Sc., Professor of Microbiology, All-India Institute of Hygiene and Public Health, 110 Chittaranjan Avenue, Calcutta.
115. KRISHNAN, M. S., A.R.C.S., Ph.D., D.I.C., Director, Bureau of Mines, Ministry of Works, Mines and Power, Central Secretariat, New Delhi. (1935).
116. KRISHNASWAMI, K. R., D.Sc., F.R.I.C., Director of Industries, Bihar, Patna. (1948).
117. KUNDU, B. C., Ph.D. (Leeds), F.L.S., Director, Jute Agricultural Research Institute, Indian Central Jute Committee, Hooghly, West Bengal. (1945).
118. LAL, R. B., M.B.B.S., D.P.H., D.T.M. & H., D.B., Professor of Vital Statistics and Epidemiology, All-India Institute of Hygiene and Public Health, 110 Chittaranjan Avenue, Calcutta. (1935).
119. LAW, S. C., M.A., B.L., Ph.D., F.Z.S., M.B.O.U., 50 Kailas Bose Street, Calcutta. (1936).
120. MACGREGOR, R. A., C.I.E., F.I.M., Technical Director, Indian Special Steel Marketing Board, 4th Floor, P23/24 Radha Bazar Street, Calcutta 1. (1948).
121. MACMAHON, P. S., M.Sc., B.Sc. (Oxon), F.I.C., I.E.S., c/o Chartered Bank of India, Australia and China, 28 Charles II Street, Haymarket, London, S.W. 1.
122. MADHAVA, K. B., M.A., A.I.A. (Lond.), Tobacco Grading Station, Kortipadu Extension, Guntur. (1940).

123. MAHABALE, T. S., M.Sc., Ph.D., Lecturer in Botany, Royal Institute of Science, Mayo Road, Bombay. (1949).
124. MAHADEVAN, C., M.A., D.Sc., Professor of Geology, Erskine College of Natural Sciences, Andhra University, Waltair. (1945).
125. MAHAJANI, G. S., M.A., Ph.D., Vice-Chancellor, Rajputana University, 18 Civil Lines, Jaipur.
126. MAHALANOBIS, P. C., O.B.E., M.A., B.Sc., F.R.S., I.E.S., Statistical Laboratories, Presidency College, Calcutta.
127. MAHANTI, P. C., D.Sc., F.Inst.P., Assoc.A.I.E.E., Ghose Professor of Applied Physics, Calcutta University, 92 Upper Circular Road, Calcutta. (1945).
128. MAHESHWARI, P., D.Sc., Professor and Head of the Department of Botany, Delhi University, Delhi. (1935).
129. MAJUMDAR, D. N., M.A., Ph.D. (Cantab), Professor of Anthropology, Lucknow University, Lucknow. (1940).
130. MAJUMDAR, G. P., Ph.D., Professor of Botany, Presidency College, Calcutta (Retired); 19 Ekdalia Place, Ballygunge, Calcutta. (1943).
131. MAJUMDAR, R. C., Dr. Phil.Nat. (Jena), Professor and Head of the Department of Physics, Delhi University, Delhi. (1941).
132. MALHOTRA, D. R., D.Sc., A.M.I.Chem.E., F.I.M., M.I.E. (India), Chief Metallurgist, B.R. & C.I. Rly., Golf Course Road, Ajmer. (1946).
133. MEHRA, H. R., M.Sc., Ph.D., Head of the Zoology Department, Allahabad University, Allahabad.
134. MEHTA, K. C., Rai Bahadur, M.Sc., Ph.D., Sc.D., Principal and Professor of Botany, Agra College, Agra.
135. MILLS, J. P., M.A., I.C.S., 4 Wilton Street, 2 Grosvenor Place, London, S.W. 1. (1936).
136. MITRA, H. K., M.Sc. (Cal.), Ph.D. (Pittsburgh, U.S.A.) Refractories Engineer, Tata Iron & Steel Co., Ltd., 12A Road East, Jamshedpur. (1949).
137. MITRA, K., M.B., D.P.H., D.T.M. & H., F.S.S. (Eng.), Nutrition Adviser, Directorate General of Health Services, New Delhi. (1949).
138. MITRA, SUBODH, M.D., F.R.C.S., F.R.C.O.G., 4 Chowringhee Terrace, Calcutta. (1944).
139. MITRA, S. C., M.A., Ph.D. (Leip.), Lecturer in Psychology, Calcutta University, 92 Upper Circular Road, Calcutta 9. (1941).
140. MITRA, S. K., M.B.E., D.Sc., Ghose Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta 9.
141. MITTER, G. C., O.B.E., M.Sc., F.R.I.C., M.Inst.Met., Chief Technical Adviser, Indian Government Mint, Bombay. (1948).
142. MITTER, P. C., M.A., Ph.D., Palit Professor of Chemistry of Calcutta University (Retired), 22 Garpar Road, Calcutta.
143. MOGHE, M.A., Ph.D., F.Z.S., Professor of Zoology, College of Science, Nagpur. (1948).
144. MOOKERJEE, H. K., D.Sc., D.I.C., Sir Nilratan Sircar Professor of Zoology and Head of the Department, Calcutta University, 35 Ballygunge Circular Road, Calcutta 19. (1939).
145. MOWDAWALLA, F. N., M.A., M.I.E.E., Mem.A.I.E.E., M.I.E., 301 Frere Road, Fort, Bombay.
146. MUKERJI, B., M.D., D.Sc., Director, Central Drugs Laboratory, Government of India, 110 Chittaranjan Avenue, Calcutta 12. (1943).
147. MUKHERJEE, J. N., C.B.E., D.Sc., F.R.I.C., F.R.A.S.B., Director, Indian Agricultural Research Institute, New Delhi.
148. MUNDKUR, B. B., Ph.D., Deputy Director (Plant Diseases and Weeds), Plant Protection and Quarantines Organization, Ministry of Agriculture; 10 Mandi House, New Delhi 3. (1946).
149. NAIK, K. G., D.Sc., F.R.I.C., Retired Principal, Baroda College, Baroda; Camp Pratapganj, B.B. & C.I. Ry.
150. NAIR, U. S., M.A., Ph.D. (Lond.), Head of the Department of Statistics, Travancore University, Trivandrum. (1945).
151. NARAYANA, BASUDEV, M.Sc., M.B., Ph.D., F.R.S.E., Principal and Professor of Physiology, Prince of Wales Medical College, Patna. (1946).
152. NARAYANAMURTI, D., B.Sc., Dr.Ing., Chief Research Officer, Composite Wood and Wood Preservation Section, Forest Research Institute, New Forest, Dehra Dun. (1940).

153. NARLIKAR, V. V., B.Sc. (Bom.), M.A. (Cantab.), F.R.A.S., Professor of Mathematics and Head of the Department, Banaras Hindu University, Banaras. (1939).
154. NATH, RAJ, Ph.D., D.I.C., University Professor and Head of the Department of Geology, Banaras Hindu University, Banaras. (1943).
155. NATH, VISHWA, M.Sc., Ph.D., F.R.M.S., Principal, Government College, Hoshiarpur. (1940).
156. NEHRU, THE HON'BLE PANDIT JAWAHARLAL, Prime Minister, Government of India, New Delhi. (1947).
157. NEOGI, P., M.A., Ph.D., I.E.S. (Retired), Principal, Maharaja Manindra Chandra College, 44A New Shambazar Street, Calcutta. (1936).
158. NORMAND, SIR CHARLES W. B., Kt., C.I.E., M.A., D.Sc., c/o Midland Bank, Gloucester Road, London, S.W. 7.
159. PAL, B. P., Ph.D., F.L.S., Head of the Division of Botany and Asst. Director, Indian Agricultural Research Institute, New Delhi. (1946).
160. PANDIT, C. G., O.B.E., M.B.B.S., Ph.D., D.P.H., D.T.M., Secretary, Indian Research Fund Association, Hutments, Room No. 15 (Civil Block) Behind South Block, New Delhi. (1939).
161. PANDYA, A. H., Sc.D. (Eng.), M.I.E. (Ind.), M.Am.Soc.C.E., A.M.I.S.E., A.M.I.W., 'Kumkum', 50-A Pedder Road, Bombay 26. (1949).
162. PANJA, G., M.B., D.Bact., Professor of Bacteriology and Pathology, School of Tropical Medicine (Retired); P. 117 Vivekananda Road, Calcutta. (1944).
163. PANSE, V. G., Ph.D., Deputy Director (Research), Institute of Plant Industry, Indore. (1946).
164. PARANJPE, G. R., O.B.E., M.Sc., A.I.I.Sc., I.E.S. (Retired), 'Sudarshan', 202/1 Sadashiv. Poona 2. (1937).
165. PARANJPYE, SIR R. P., Kt., D.Sc., Purushottam Ashram, Poona 4.
166. PARIJA, P., O.B.E., M.A., D.Sc., I.E.S., Pro-Vice-Chancellor, Banaras Hindu University, Banaras.
167. PARTHASARATHY, N., B.Sc. Ag., Ph.D. (Lond.), Geneticist, Indian Agricultural Research Institute, New Delhi. (1949).
168. PASRICHA, C. L., M.A., M.B., B.Chir., M.R.C.S., L.R.C.P., Lt.-Col., I.M.S., Chief Medical Adviser to the High Commissioner, India House Aldwych, London, W.C. 2. (1939).
169. PERCIVAL, F. G., O.B.E., Ph.D., F.G.S., Sadlers Cottage, Haslemore, Surrey, England. (1936).
170. PICHAMUTHU, C. S., Ph.D., D.Sc. (Glasgow), F.R.S.E., F.G.S., Director of Geology, Mysore Geological Department, Bangalore 1. (1942).
171. PRASAD, B. N., D.Sc. (Paris), Ph.D. (Liverpool), Professor and Head of the Department of Mathematics, Science College, Patna University, Patna. (1936).
172. PRASAD, MATA, D.Sc., F.R.I.C., Principal, Royal Institute of Science, Mayo Road, Bombay. (1935).
173. PRASHAD, BAINI, O.B.E., D.Sc., F.R.S.E., F.L.S., F.Z.S., F.R.A.S.B., Fisheries Development Adviser, Government of India, Ministry of Agriculture; 13 Tughlaq Road, New Delhi.
174. PRUTHI, H. S., Ph.D., Sc.D. (Cantab.), F.R.A.S.B., Plant Protection Adviser, Government of India, Ministry of Agriculture; 12 Akbar Road, New Delhi.
175. QURESHI, MUZAFARUDDIN, Ph.D., Director of Scientific and Industrial Research, H.E.H. Nizam's Government, Hyderabad (Deccan).
176. RACINE, C., S.J., Dr. ès Sc. (Paris), Professor and Head of the Department of Mathematics, Loyola College, Madras. (1949).
177. RAJ, B. SUNDARA, Diwan Bahadur, M.A., Ph.D., Fisheries Development Officer, U.P., Civil Secretariat, Lucknow. (1935).
178. RAJU, S. P., B.E., Dr. Ing. (Paris), 'Hill View', Red Hills, Hyderabad (Deccan). (1948).
179. RAKSHIT, H., D.Sc., F.Inst.P., Professor of Physics, Bengal Engineering College, Botanic Gardens P.O., Howrah. (1943).
180. RAMANATHAN, K. R., Diwan Bahadur, M.A., D.Sc., Physical Research Laboratory, Navarangpura, Ahmedabad.
181. RAMANUJAM, S., Ph.D., Director, Central Potato Research Institute, Post Box No. 136, Patna. (1948).
182. RAMDAS, L. A., M.A., Ph.D., Director of Agricultural Meteorology, Meteorological Office, Poona 5. (1935).

183. RAMIAH, K., M.B.E., L.Ag., M.Sc., Dip.Agr. (Cantab.), Director, Central Rice Research Institute, P.O. Naya Bazar, Cuttack. (1942).
184. RANDHAWA, M. S., M.Sc., I.C.S., Director-General, Rehabilitation (Rural), Civil Secretariat, Jullundur, E. Punjab. (1943).
185. RANGASWAMI AYYANGAR, G. N., Rao Bahadur, B.A., I.A.S. (Retired), Professor of Botany, Andhra University; Siripuram House, Uplands, Waltair.
186. RAO, B. RAMA, M.A., D.I.C., F.G.S., Joint Director, Bureau of Mines, Ministry of Works, Mines and Power, Central Secretariat, New Delhi.
187. RAO, B. SANJIVA, M.A., Ph.D., D.Sc. (Lond.), H.E.H. Nizam Professor of Inorganic and Mineral Chemistry, Indian Institute of Science, Malleswaram, Bangalore. (1944).
188. RAO, H. SRINIVASA, M.A., D.Sc., Chief Research Officer, Central Marine Fisheries Research Station, Triplicane P.O., Madras. (1937).
189. RAO, K. RANGADHAMA, D.Sc. (Madras and London), Professor of Physics, Andhra University, Waltair. (1937).
190. RAO, L. RAMA, M.A., F.G.S., Professor of Geology, Central College, Bangalore. (1939).
191. RAO, M. V. RADHAKRISHNA, M.B., B.S., Ph.D. (Andhra), Assistant Director, Haffkine Institute, Parel, Bombay. (1945).
192. RAO, S. RAMACHANDRA, Ph.D., D.Sc., Professor of Physics, Central College, Bangalore. (1948).
193. RAY, J. C., M.D., Director, Indian Institute for Medical Research, 15 Roy Mansion, Calcutta 20. (1948).
194. RAY, J. N., D.Sc., Ph.D., F.R.I.C., Deputy Director-General (Development), Directorate General of Industries and Supplies, Shahjahan Road, New Delhi. (1935).
195. RAY, P. R., M.A., Palit Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta 9.
196. RAY, R. C., D.Sc. (Lond.), F.R.I.C., Emeritus Professor of Chemistry, Science College, Patna; B.M. Das Road, Bankipore, Patna. (1943).
197. ROONWAL, M. L., M.Sc., Ph.D. (Cantab.), Major, Forest Entomologist, Forest Research Institute, New Forest, Dehra Dun. (1945).
198. ROW, R., M.D., D.Sc., Lt.-Col., I.M.S. (Hon.), 37 New Marine Lines, Fort, Bombay 1.
199. ROY, S. C., D.Sc., F.R.Met.Soc. (Lond.), Deputy Director-General of Observatories (Instruments and Supplies), India Meteorological Department, Lodi Road, New Delhi. (1940).
200. ROY, S. K., Ph.D., In-charge of Development of Coal Mines, Dabor Colliery, P.O. Shamdih, Dist. Burdwan (via Sitampur), E.I. Ry. (1940).
201. ROY, S. N., M.Sc., Lecturer in Statistics, Presidency College, Calcutta. (1944).
202. SAHA, M. N., D.Sc., F.R.S., F.R.A.S.B., Palit Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta 9.
203. SARKAR, P. B., Dr. es. Sc., A.I.C., Ghose Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta 9. (1935).
204. SARKAR, P. B., D.Sc. (Dacca), Director of Technological Research Laboratories, Indian Central Jute Committee; P 133B Lake Terrace, Calcutta 29. (1946).
205. SAVUR, S. R., M.A., L.T., Ph.D., Regional Director, The Observatory, 15 Mowbrays Road, Teynampet P.O., Madras. (1941).
206. SEN, B. M., M.A., M.Sc., I.E.S. (Retired), 12 Ballygunge Circular Road, Ballygunge, Calcutta 19.
207. SEN, J. M., Rai Bahadur, B.Sc., M.Ed. (Leeds), Dip.Ed. (Oxford), T.D. (London), F.R.G.S., 28 New Road, Alipur, Calcutta. (1935).
208. SEN, K. C., D.Sc., Director of Dairy Research, Indian Dairy Research Institute, Hosur Road, Bangalore. (1949).
209. SEN, N. R., D.Sc., Ph.D., Ghose Professor of Applied Mathematics, Calcutta University, 92 Upper Circular Road, Calcutta 9.
210. SESHADRI, T. R., M.A., Ph.D. (Manchester), Professor of Chemistry, Delhi University, Delhi. (1942).
211. SETNA, S. B., M.Sc., Ph.D. (Cantab.), F.R.M.S., Director of Fisheries, Bombay, Old Custom House Yard, Bombay. (1943).
212. SEWELL, R. B. SEYMOUR, Lt.-Col., C.I.E., M.A., Sc.D., F.R.S., M.R.C.S., L.R.C.P., F.Z.S., F.L.S., F.R.A.S.B., 18 Barrow Road, Cambridge. (1936).
213. SHAH, R. C., M.Sc., Ph.D. (Lond.), Professor of Organic Chemistry, Royal Institute of Science, Mayo Road, Bombay. (1941).

214. SHARIF, M., D.Sc., Ph.D., Asst. Director, I/c Entomology Department, Malaria Institute of Pakistan, Karachi. (1939).
215. SIDDIQI, M. R., M.A., Ph.D., Director, Research Institute, Osmania University, Hyderabad (Deccan). (1937).
216. SINGH, B. K., M.A., Sc.D., F.R.I.C., I.E.S., Honorary Research Professor of Chemistry, Banaras Hindu University, Banaras.
217. SINGH, B. N., D.Sc., Crop Physiologist, Institute of Crop Physiology, U.P. Government, Butler Palace, Lucknow. (1941).
218. SIRKAR, S. C., D.Sc., Professor of Physics, Indian Association for the Cultivation of Science, 210 Bowbazar Street, Calcutta. (1942).
219. SOHONI, V. V., B.A. (Hons.), M.Sc., Deputy Director-General, India Meteorological Department, Lodi Road, New Delhi. (1942).
220. SOKHEY, SIR S. S., Kt., M.A., M.D., D.T.M. & H., Major-General, I.M.S., Director, Haffkine Institute, Parel, Bombay.
221. SONDHI, V. P., M.B.E., M.Sc., F.G.S., Dy. Director (Min. Dev.), Geological Survey of India, 27 Chowringhee Road, Calcutta. (1941).
222. SOPARKAR, M. B., M.D., B.Hy., 117 Ghodbunder Road, Khar, Bombay 21. (1937).
223. SPENCER, E., D.Sc., Ph.D., F.R.I.C., A.R.S.M., M.I.M.M., F.G.S., Ashfield House, Keighley Road, Colne, Lanes., England.
224. SRIVASTAVA, B. N., D.Sc., Lecturer in Physics, Lucknow University, Lucknow. (1946).
225. SRIVASTAVA, P. L., Rai Sahib, M.A., D.Phil., Reader in Mathematics, Allahabad University, Allahabad. (1935).
226. SUBRAHMANYAN, V., D.Sc., F.R.I.C., Planning Officer, Central Food Technological Research Institute, Cheluvamba Mansion, V. V. Mohalla P.O., Mysore.
227. SUKHATME, P. V., D.Sc. (Lond.), Ph.D., Statistical Adviser, Indian Council of Agricultural Research, 'P' Block, Raisina Road, New Delhi. (1943).
228. SUR, N. K., D.Sc., Professor of Meteorology, Andhra University, Waltair. (1938).
229. TAWDE, N. R., M.Sc., Ph.D. (Lond.), F.Inst.P., Professor of Physics, Royal Institute of Science, Mayo Road, Bombay. (1942).
230. TAYLOR, SIR JOHN, Kt., C.I.E., D.S.O., M.D., D.P.H., LL.D., Major-General, I.M.S. (Retired), 88 Onslow Gardens, Kensington, London, S.W. 7.
231. TOSHNIWAL, G. R., D.Sc., S.M.I.R.E., Managing Director, Toshniwal Bros. Ltd., Lady Jamshedji Road, Mahim, Bombay 16. (1943).
232. TRIBEDI, B. P., M.B. (Cal.), D.B. (Lond.), Professor of Pathology, Medical College and Bacteriologist to the Government of West Bengal, Calcutta. (1943).
233. UKIL, A. C., M.B., M.S.P.E., F.S.M.F. (Hon. causa), 67 Dharamtala Street, Calcutta 13. (1935).
234. UPPAL, B. N., M.B.E., Ph.D., Director of Agriculture, Bombay Province, Poona 5. (1944).
235. VACHELL, E. T., M.A. (Cantab.), F.G.S., F.Inst.P., Coley, Lydwell Road, Torquay, Devon., England. (1942).
236. VENKATARAMAN, K., M.S. Tech., Ph.D., D.Sc., Director, Department of Chemical Technology, Bombay University, Matunga Road, Bombay. (1939).
237. VENKATESACHAR, B., Rao Bahadur, M.A., F.Inst.P., Ambika Vilas, 62 Gandhi Bazar St., Basavangudi, Bangalore.
238. VARMA, R. S., D.Sc., Senior Scientific Officer, Ministry of Defence, Government of India, South Block, Central Secretariat, New Delhi. (1949).
239. VERMAN, L. C., B.S.Eng., M.S., Ph.D. (Cornell), F.Inst.P., Director, Indian Standards Institution, 19 University Road, Delhi. (1946).
240. VIJAYARAGHAVAN, T., Ph.D. (Oxon), Krishnavilas, Vepery, Madras.
241. VISWANATH, B., D.Sc., F.R.I.C., Director of Agriculture, Rajasthan Union, Jaipur.
242. WADIA, D. N., M.A., D.Sc. (Hon.), F.G.S., F.R.A.S.B., Geological Adviser to the Department of Scientific Research, Government of India, 10 King George's Avenue, New Delhi.
243. WEST, W. D., M.A., Sc.D. (Cantab.), F.R.A.S.B., Director, Geological Survey of India, 27 Chowringhee Road, Calcutta.
244. WHEELER, T. S., D.Sc., Ph.D., F.R.C.Sc.I., F.R.I.C., F.Inst.P., M.I.Chem.E., Professor of Chemistry, University College of Dublin (National University of Ireland), Upper Merrion Street, Dublin.
245. YAJNIK, N. A., M.A., D.Sc., A.I.C., 17 Manchubhai Road, Malad (Bombay Suburb). (1940).

HONORARY FELLOWS

1. APPLETON, E. V., M.A., D.Sc., F.R.S., N.L., Secretary, Department of Scientific and Industrial Research of Great Britain, London. (1939).
 2. BAILEY, E. B., Kt., D.Sc., LL.D., F.R.S., Formerly Director-General, Geological Survey of Great Britain, 10 Greenhill Gardens, Edinburgh. (1941).
 3. BLAKESLEE, A. F., D.Sc., Ph.D., LL.D., Director of Genetics Experiment Station, Smith College, Northampton, U.S.A. (1945).
 4. BOHR, NIELS, N.L., Director, Copenhagen Institute of Theoretical Physics, Copenhagen, Denmark. (1935).
 5. BURN, J. H., M.D., F.R.S., Professor of Pharmacology, Oxford University, Oxford. (1947).
 6. CHRISTOPHERS, SIR RICKARD, Kt., C.I.E., O.B.E., M.D., Brevet-Colonel, I.M.S. (Retired), 186 Huntingdon Road, Cambridge. (1940).
 7. DALE, SIR HENRY HALLETT, Kt., O.M., G.B.E., M.A., M.D., F.R.C.P., Hon.D.Sc., Hon.M.D., Hon. LL.D., F.R.S., Formerly Director of the Davy-Faraday Research Laboratory and Fullerian Professor of Chemistry in the Royal Institution, London; 54 Campden Hill Court, Kensington, London, W. 8. (1944).
 8. DIRAC, P. A. M., F.R.S., N.L., Lucasian Professor of Mathematics, Cambridge University, Cambridge. (1947).
 9. DONNAN, F. G., F.R.S., Formerly Director, Sir William Ramsay Laboratory, University College, London; 23 Woburn Square, London, W.C. 1. (1936).
 10. EINSTEIN, ALBERT, N.L., Princeton University, 112 Mercer Street, New Jersey, U.S.A. (1935).
 11. FISHER, R. A., Sc.D., F.R.S., Professor of Genetics, Cambridge University; Whittinghame Lodge, 44 Storey's Way, Cambridge. (1939).
 12. GOODRICH, F. S., M.A., D.Sc., F.R.S., Linacre Professor of Zoology and Comparative Anatomy, University Museum, Oxford. (1941).
 13. GREENWOOD, MAJOR M., D.Sc., F.R.C.P., F.R.S., Formerly Professor of Epidemiology and Vital Statistics, London School of Tropical Medicine and Hygiene; Hill Crest, Church Hill, Loughton, Essex. (1941).
 14. HILL, A. V., O.B.E., Sc.D., F.R.S., N.L., M.P., Foulerton Research Professor, University College, London. (1944).
 15. LAWRENCE, E. O., Radiation Laboratory, California University, Berkeley, U.S.A. (1941).
 16. MARSHALL, SIR GUY A. K., C.M.G., F.R.S., Director, Imperial Institute of Entomology, London. (1935).
 17. MILLIKAN, R. A., President of the California Institute of Technology, Pasadena, U.S.A. (1945).
 18. NIGGLI, P., Professor of Mineralogy and Petrology, Federal Polytechnical University and University of Zurich. (1945).
 19. ROBINSON, SIR ROBERT, D.Sc., F.R.S., N.L., Waynflete Professor of Organic Chemistry in the Dyson Perrins Laboratory, Oxford University. (1937).
 20. RUSSELL, SIR E. JOHN, D.Sc., F.R.S., Formerly Director, Rothamsted Agricultural Experimental Station, Campsfield Wood, Woodstock, Oxon England. (1938).
 21. SHERRINGTON, SIR CHARLES S., O.M., G.B.E., F.R.S., N.L., Formerly Waynflete Professor of Physiology in the University of Oxford; Broomside, Valley Road, Ipswich, England. (1935).
 22. SZENT-GYÖRGYI, A., N.L., Professor of Biochemistry, University of Budapest, Budapest, Hungary. (1947).
 23. UREY, HAROLD C., N.L., Professor of Chemistry, Institute of Nuclear Studies, University of Chicago, Chicago 37, Illinois. (1947).
 24. WENYON, C. M., C.M.G., G.B.E., F.R.S., Director-in-Chief, Wellcome Bureau of Scientific Research, 183 Euston Road, London, N.W. 1. (1937).
-

APPENDIX II

COMMITTEES

SECTIONAL COMMITTEES, 1950

(1) 'Mathematics' Committee for Mathematics, Astronomy and Geodesy:—

To serve until
Dec. 31

Prof. Ram Behari	1950
Prof. V. V. Narlikar	1950
Prof. N. R. Sen (Secretary and Convener)	1951
Dr. P. V. Sukhatme	1951
Prof. M. R. Siddiqi	1952
Dr. P. L. Srivastava	1952

(2) 'Physics' Committee for Physics and Meteorology:—

Prof. H. J. Bhabha	1950
Dr. R. N. Ghosh	1950
Prof. S. K. Mitra (Secretary and Convener)	1951
Dr. S. K. Banerji	1951
Dr. D. M. Bose	1952
Prof. D. S. Kothari	1952

(3) 'Chemistry' Committee for Pure and Applied Chemistry:—

Dr. J. N. Ray	1950
Dr. B. C. Guha	1950
Dr. S. Krishna	1951
Prof. B. B. Dey (Secretary and Convener)	1951
Dr. S. S. Bhatnagar	1952
Dr. J. C. Ghosh	1952

(4) 'Engineering Sciences' Committee for Engineering, Metallurgy, Electrotechnics and kindred subjects:—

Dr. S. P. Raju	1950
Mr. P. C. Bose	1950
Dr. H. K. Mitra	1951
Dr. A. H. Pandya (Secretary and Convener)	1951
Prof. P. C. Mahanti	1952
Mr. F. N. Mowdawalla	1952

(5) 'Geology' Committee for Geology, Palaeontology, Mineralogy and Geography:—

Prof. C. S. Pichamuthu	1950
Dr. W. D. West (Secretary and Convener)	1950
Dr. D. N. Wadia	1951
Dr. P. K. Ghosh	1951
Dr. M. S. Krishnan	1952
Prof. Raj Nath	1952

(6) 'Botany' Committee for Pure and Applied Botany, Forestry and Agronomy:—

Dr. B. S. Kadam	1950
Mr. M. S. Randhawa	1950
Prof. P. Maheshwari	1951
Dr. P. Parija (Secretary and Convener)	1951
Prof. G. P. Majumdar	1952
Dr. B. P. Pal	1952

To serve until
Dec. 31

Dr. S. L. Hora (Secretary and Convener)	..	..	..	..	1950
Dr. Baini Prashad	..	..	..	..	1950
Prof. K. N. Bahl	..	..	..	..	1951
Dr. D. N. Majumdar	..	..	..	..	1951
Prof. Vishwa Nath	..	..	..	..	1952
Dr. H. S. Pruthi	..	..	..	..	1952

Dr. K. C. Sen	1950
Dr. B. Mukerji (Secretary and Convener)	1950
Dr. C. G. Pandit	1950
Dr. B. Narayana	1951
Dr. M. V. Radhakrishna Rao	1951
Dr. V. R. Khanolkar	1951
Prof. K. N. Bagchi	1952
Dr. B. B. Dikshit	1952
Prof. J. M. Sen	1952

Dr. J. N. Mukherjee (Convener)
and Conveners of all Sectional Committees.

The President.
The Treasurer.

The two Secretaries.
Dr. S. K. Banerji.

Dr. D. N. Wadia.

Office-bearers and Conveners of All Sectional Committees.

The President	} <i>ex-officio</i> .	Dr. D. N. Wadia	..	Geology.
The Treasurer		Dr. P. Parija	..	Botany.
The two Secretaries		Prof. K. N. Bahl	..	Zoology.
Prof. A. C. Banerji		..	Dr. B. Mukerji	..
Dr. S. K. Banerji	..	Dr. S. L. Hora.		
Dr. J. C. Ghosh	..	Sir S. S. Sokhey.		

(Functioned up to 31st March, 1949)

The President	} <i>ex-officio.</i>	<i>Chemistry</i>	..	Dr. J. C. Ghosh.
The Treasurer				Dr. S. Krishna.
The two Secretaries				Prof. B. B. Dey.
<i>Physics</i>	Prof. H. J. Bhabha.	<i>Biology</i>	..	Dr. S. P. Agharkar.
	Dr. R. N. Ghosh.			Dr. S. L. Hora.
	Prof. S. K. Mitra.			Dr. B. P. Pal.

EDITORIAL BOARD, 1949

	Editor of Publications	..	Dr. S. L. Hora.
Mathematics	.. Prof. N. R. Sen.	Botany	.. Prof. S. P. Agharkar.
Physics	.. Dr. K. S. Krishnan.	Zoology	.. Prof. K. N. Bahl.
Chemistry	.. Prof. B. B. Dey.	Anthropology	.. Dr. B. S. Guha.
Geology	.. Dr. W. D. West.	Physiology	.. Prof. K. N. Bagchi.

LIBRARY COMMITTEE, 1949

The President	} <i>ex-officio</i> .	Prof. A. C. Banerji.
The Treasurer		Dr. S. L. Hora.
The two Secretaries		Prof. R. C. Majumdar.
		Dr. Bains Prashad.

CHANDRAKALA HORA MEMORIAL ADVISORY BOARD, 1949

Dr. T. J. Job.	Dr. S. L. Hora	} <i>Donors (ex-officio)</i> .
Dr. M. L. Roonwal.	Mrs. Vidya Vati Hora	
Dr. Bains Prashad.		

STANDING COMMITTEE FOR ORGANIZATION OF SYMPOSIA

Prof. B. B. Dey.	Prof. M. N. Saha.
Prof. B. C. Guha.	Dr. A. C. Ukil (Convener).
	Dr. D. N. Wadia.

**COMMITTEE TO EXPLORE POSSIBILITIES OF CARRYING ON ADVANCED
SCIENTIFIC TEACHING AND RESEARCH IN AN INDIAN
LANGUAGE AND THE QUESTION OF THE SCRIPT
IN WHICH THIS COULD BE DONE ***

(Appointed August 1947.)

The President.	Prof. D. D. Kosambi.
Prof. S. P. Agharkar.	Dr. D. S. Kothari.
Prof. A. C. Banerji.	Dr. K. S. Krishnan.
Prof. H. J. Bhabha (Convener).	Dr. J. N. Mukherjee.
Prof. S. N. Bose.	Dr. B. B. Dey.
	Prof. N. R. Sen.

The Committee was requested to consult, among others, the following:—

Dr. Tara Chand.	Dr. Zakir Hussain.
Dr. Suniti Kumar Chatterji.	Prof. Humayun Kabir.
Maulvi Abdul Haq.	Prof. K. Swaminathan.
	Dr. Raghu Vira.

**COMMITTEE (WITH POWERS TO CONSULT EXPERTS) TO SUGGEST
A PROPER EMBLEM (CREST) FOR THE INSTITUTE AND TO
RECOMMEND A SUITABLE DESIGN FOR THE CHANDRA-
KALA HORA MEMORIAL MEDAL**

(Appointed January 1948.)

The President	} <i>ex-officio</i> .	Prof. H. J. Bhabha.
The Treasurer		Dr. S. L. Hora (Convener).
The Secretaries		Dr. J. N. Mukherjee.
		Major-General S. S. Sokhey.

The Committee was requested to consult, among others, the following:—

Dr. Suniti Kumar Chatterji.	Nawab Zain Yar Jung.
-----------------------------	----------------------

* The Committee has submitted its Final Report.

COMMITTEE TO REVIEW THE RULES OF THE INSTITUTE **(Appointed August 1948.)*

Prof. S. P. Agharkar.

Prof. K. N. Bagchi (Convener).

The two Secretaries.

Dr. S. L. Hora.

Prof. J. M. Sen.

**COMMITTEE TO REVIEW THE ADMINISTRATION OF PUBLICATION
GRANT AND TO GO INTO THE QUESTION OF MERGER OF TWO
OR MORE SOCIETIES OF ALLIED NATURE ****(Appointed August 1948.)*

Prof. S. P. Agharkar.

Prof. S. N. Bose.

The Secretaries.

Dr. S. L. Hora.

Prof. J. M. Sen.

PUBLICATION ADVISORY BOARD*

Editor of Publications (Convener)

and Members of Council resident in Calcutta.

**COMMITTEE TO FORMULATE A SCHEME FOR FORMATION OF NATIONAL
COMMITTEES IN DIFFERENT BRANCHES OF SCIENCE***(Appointed January 1949.)*

Prof. S. P. Agharkar.

Prof. A. C. Banerji.

Prof. D. S. Kothari.

Dr. J. N. Mukherjee (Convener).

Prof. J. M. Sen.

Representatives of Scientific Societies concerned.

**COMMITTEE TO CONSIDER THE QUESTION OF RE-ORGANIZATION
OF THE BOTANICAL SURVEY OF INDIA***(Appointed August 1949.)*

Prof. S. R. Boso.

Prof. P. Parija.

Prof. A. C. Joshi.

APPENDIX III**IMPORTANT RESOLUTIONS OF THE COUNCIL**

January 4, 1949.—Decided to urge upon the Government of India the need of establishing a high power computation laboratory for (a) statistical work (correlation up to 12 variants), (b) numerical calculations arising in problems of Applied Mathematics, Applied Physics, Engineering and Aeronautics, and (c) construction of mathematical tables. At least eight properly qualified scientists should be sent abroad to suitable institutions for training in this highly specialized work. Before this was undertaken, it would be essential to prepare a complete plan from the very start, and, it was therefore desirable that the Government should immediately appoint a Sponsoring Committee consisting of a minimum of three and a maximum of five members representing physical, engineering and statistical sciences.

RESOLVED that in the opinion of the Council the adoption by India of the Metric System of weights and measures and coinage is ultimately desirable. Also International terms as far as possible should be followed in scientific literature.

March 4, 1949.—The Government of India having desired clarification in respect of principles governing 'recognition' of scientific societies, it was decided to advise that—

- (a) The 'recognition' by the Government of India will mean that the society represents expert scientific opinion relating to the subject cultivated by it and will be deserving Government assistance in respect of its publications and projects for promotion of knowledge.

* The Committee has submitted its Final Report.

- (b) In a country of the size of India, more than one society covering the same science was to be expected and each request for help will have to be judged on its merits.
- (c) The National Institute would be a suitable agency for co-ordinating the contributions of different Government agencies to the same society and the Institute will be glad to take up the work.
- (d) 'Recognition' should confer the privilege of using a suitable abbreviation after their names by the members of the society so recognised.

August 5, 1949.—RESOLVED that the Government of India in the Ministry of Education be informed as follows:—

'The Council of the National Institute has come to the general conclusions given below on the question of the possibility of carrying on advanced scientific teaching and research in an Indian language and the script in which this could be done:—

- (1) It is considered possible to give instruction up to the graduate level in any provincial language or national language, but it is desirable to leave latitude and allow flexibility in this matter so that each institution can develop a practice which best serves the needs of the locality in which it is situated and the community it serves.
- (2) At the post-graduate stage the medium of instruction could be any language agreed upon by the teacher and the students.
- (3) It is desirable that attempts should be made to uniformise Indian scripts as far as possible so as to reduce the differences between languages of the same linguistic group.
- (4) For the advanced scientific and research journals published by learned societies, publication should be permitted not only in the national language but also in any of the major provincial languages and in English. In each case the article should always be followed by a summary or abstract in the national language and in English. This conforms to the practice in multi-lingual states such as the Soviet Union. The Council feels that the foreign circulation of scientific journals carrying either complete papers or abstracts in Indian languages would help to spread a knowledge of these Indian languages abroad.
- (5) International scientific terms should always be used except when there are in any particular Indian language well-established words in common use whose meaning is unambiguous. The Council does not favour the attempt to invent new Indian equivalents for international scientific terms and is of the considered opinion that such a procedure will have an adverse effect on the growth of Indian science.

Based on the above conclusions, the Council wishes to recommend that it is essential for every science student to know at least one of the following foreign languages: English, French, German, Italian or Russian, and that for those knowing only one foreign language a knowledge of English is to be preferred. It is to be noted that advanced scientific workers in any country have, practically without exception, enough working knowledge of English to be able to read specialized papers in their own subjects in English. Some members were of the view that a knowledge of English should be a pre-requisite for admission of students to science classes in the universities and it is considered important that science students should be made familiar with English from a very early age.

The above recommendation is made in view of the fact that, on an average, approximately one new scientific text-book or treatise on some specialized scientific subject appears per day in some one of the languages mentioned above; and whereas it is necessary for a scientific worker to be able to read those which appear in his own subject, it is clearly impossible for him to do so if he can read one, or even more, of the Indian languages only. At the present stage it is impossible for a man to acquire a wide knowledge of his subject by limiting himself to reading books published in any, or even all, of the Indian languages only, and this situation is not likely to be materially altered within the next twenty years. The translation into the Indian languages of specialized scientific books can only be done by men of science, and any attempt to carry out such a programme with the limited scientific personnel available in India at present—which is, in any case, far short of the country's scientific and technical demands—would cripple its scientific and technical development.'

RESOLVED that the Government of India may be advised that the subject of 'Protection of Nature' being of particular importance for India, where many of our natural resources in soil, plants and animals are being wasted, the Government of India should assist in the formation of an International Union for the Protection of Nature, and that non-official organisations interested in the protection of Nature should be actively encouraged and their representation on the International Union through a National Committee should be facilitated.

RESOLVED that the Government of India may be advised to form a National Section of the International Committee for Bird Preservation, and this be done through the Zoological Survey of India.

RESOLVED that the Government of India may be advised to participate in the scheme for a permanent machinery for collaboration and interchange of geological information between Commonwealth Governments.

October 7, 1949.—RESOLVED that the Government of India be advised to become a member of the British Scientific Instruments Research Association.

APPENDIX IV

LIST OF PERIODICALS RECEIVED IN 1949

ASIA

India—

1. Annals of Biochemistry and Experimental Medicine.
2. Annual Report of Bose Research Institute.
3. Annual Report of the Imperial Veterinary Research Institute.
4. Annual Report of the Indian Central Cotton Committee.
5. Annual Report of Indian Lac Research Institute.
6. Annual Report of Indian Standards Institution.
7. Annual Return of Statistics relating to Forest Administration in British India for year 1940-41.
8. Bulletin of the Calcutta Mathematical Society.
9. Bulletin of the National Geographical Society.
10. Bulletin of the Indian Standards Institution.
11. Calcutta Geographical Review.
12. Calcutta Statistical Association Bulletin.
13. Census of India ; Papers.
14. Current Science.
15. Eastern Anthropologist.
16. Forest Research in India.
17. Immunity Bulletin.
18. Indian Cotton Growing Review.
19. Indian Dairyman.
20. Indian Farming.
21. Indian Forest Bulletin.
22. Indian Forester.
23. Indian Forest Records.
24. Indian Journal of Agricultural Science.
25. Indian Journal of Dairy Science.
26. Indian Journal of Genetics and Plant Breeding.
27. Indian Journal of Medical Research.
28. Indian Journal of Pharmacy.
29. Indian Journal of Physics.
30. Indian Standards.
31. Indian Journal of Veterinary Science and Animal Husbandry.
32. Indian Medical Gazette.
33. Indian Minerals.
34. Industrial and News Section of the Indian Chemical Society.
35. International Medical Abstracts.
36. Journal of the Indian Chemical Society.
37. Journal of the Indian Mathematical Society.
38. Journal of Indian Society of Agricultural Statistics.
39. Journal of Scientific and Industrial Research.
40. Kheti.
41. Man in India.
42. Mathematics Student.
43. Memoirs of the Indian Meteorological Department.
44. Mysore Geological Department Records.
45. Physics Quarterly.
46. Proceedings of the Indian Academy of Science, Sections A and B.
47. Proceedings of the National Academy of Sciences, Sections A and B.
48. Proceedings of the Society of Biological Chemists.
49. Proceedings of the Zoological Society of Bengal.
50. Progress Report of the Institute of Plant Industry.

51. Quarterly Journal of the Geological, Mining and Metallurgical Society of India.
52. Report of the Botanical Survey of India.
53. Report of the Haffkine Institute.
54. Report of the King Institute of Preventive Medicine.
55. Report of the Session of the 1st Conference of the Indian National Commission for Co-operation with UNESCO.
56. Science and Culture.
57. Scientific Notes of the India Meteorological Department.
58. Seismological Bulletin of the Meteorological Department.
59. Technological Bulletin of the Indian Central Cotton Committee.
60. Technical Reports of the Survey of India.
61. Transactions of the Indian Institute of Metals.
62. Transactions of the Mining, Geological and Metallurgical Institute of India.

China—

1. Botanical Bulletin of Academia Sinica.
2. Bulletin of the Oceanic Institute of Taiwan.
3. Science Record, Shanghai.

East Indies—

1. Bulletin of the Botanic Gardens, Buitenzorg.
2. Treubia.

Philippines—

Philippine Journal of Science, Manila.

AUSTRALASIA

Australia—

1. Journal and Proceedings of the Royal Society of New South Wales.
2. Papers and Proceedings of the Royal Society of Tasmania.
3. Report of the Department of Mines, Western Australia.

New Zealand—

1. Bulletin of the Auckland Institute and Museum.
2. The New Zealand Journal of Science and Technology, Sections A and B.
3. Transactions and Proceedings of the Royal Society of N. Zealand.
4. Records of the Auckland Institute and Museum.

AFRICA

Union of South Africa—

1. Annals of the South African Museum.
2. Circulars of Union Observatory, Union of S. Africa.
3. Transactions of the Royal Society of South Africa.

Sudan—

Sudan Notes and Records.

NORTH AMERICA

Canada—

1. Contributions of Dominion Observatory, Ottawa, Canada.
2. Proceedings of the Nova Scotia Institute of Science, Halifax, N.S.
3. Proceedings of the Royal Canadian Institute, Toronto.
4. Proceedings of the Royal Canadian Institute, Series IIIA.
5. Publications of Dominion Observatory, Ottawa.
6. Transactions of the Royal Society of Canada, Ottawa.

United States—

1. American Journal of Physics.
2. Annals of Harvard College Observatory.
3. Annals of New York Academy of Sciences, New York.
4. Annual Report of the Harvard College Astronomical Observatory.

5. Annual Report of the Director, Purdue University, [Lafayette.
6. Annual Report of the Rockefeller Foundation, New York.
7. Annual Report of the Rockefeller Foundation (International Health Division).
8. Biological Abstracts.
9. Biological Bulletin (Marine Biological Laboratory, Woods Hole).
10. Bulletin of the American Museum of Natural History, New York.
11. Bulletin of California Agricultural Experiment Station, Berkeley.
12. Bulletin of Cornell University Agricultural Experiment Station.
13. Bulletin of Harvard College Astronomical Observatory.
14. Bulletin of the Geological Survey, U.S. Department of the Interior.
15. Bulletin of the Tropical Plant Research Foundation, Washington.
16. Bulletin of the United States National Museum, Smithsonian Institution.
17. Bulletin of Scripps Institution of Oceanography, University of California, Berkeley.
18. Chemical Abstracts.
19. Chemical Reviews.
20. Circulars of the California Agricultural Extension Service.
21. Circulars of the California Agricultural Experiment Station.
22. Circulars of Harvard College, Observatory.
23. Circulars of Purdue University, Agricultural Experiment Station.
24. Contributions from the U. S. National Herbarium (United States National Museum).
25. F.A.O. Bulletins.
26. Fieldiana—Geology (Chicago Natural History Museum).
27. Fieldiana—Geology (Memoirs), (Chicago Natural History Museum.)
28. Harvard Reprints (Harvard College Observatory).
29. Harvard Reprints, Series II (Harvard College Observatory).
30. Hilgardia.
31. Information Bulletin of the Inter-American Institute of Agricultural Sciences.
32. Journal of Chemical Physics.
33. Journal of the Elisha Mitchell Scientific Society, University of Carolina.
34. Journal of the Franklin Institute.
35. Journal of the Optical Society of America.
36. Journal of Physical and Colloid Chemistry, Baltimore.
37. Journal of Research (National Bureau of Standards).
38. Journal of Washington Academy of Sciences.
39. Mathematics Magazine.
40. Mathematics Review (American Mathematical Society).
41. Mathematics Teacher.
42. Memoirs of Cornell University Agricultural Experiment Station.
43. Memoirs of San Diego Society of Natural History.
44. Novitates of American Museum of Natural History.
45. Nucleonics.
46. Nursery Notes (Department of Horticulture, Ohio State University).
47. Occasional Papers of the California Academy of Sciences.
48. Technical News Bulletin (National Bureau of Standards).
49. Physical Review.
50. Proceedings of the California Academy of Sciences.
51. Proceedings of the Louisiana Academy of Sciences.
52. Proceedings of the National Academy of Sciences of the U.S.A., Washington.
53. Proceedings of U.S. National Museum, Smithsonian Institution.
54. Proceedings (Reprints) of U.S. National Museum, Smithsonian Institution.
55. Proceedings of the Utah Academy of Sciences, Arts and Letters.
56. Professional Papers of the Geological Survey, U.S. Dept. of the Interior.
57. Public Health Reports.
58. Public Health Reports (Supplements).
59. Publications in Botany, University of California.
60. Quarterly of Applied Mathematics, Brown University.
61. Quarterly Progress Reports, Research Laboratory of Electronics (M.I.T.).
62. Records of Observations (University of California Oceanographic Observations on the E.W. 'Scripps' Cruises).
63. Tropical Contributions of the Tropical Plant Research Foundation.
64. Science.
65. Scripta Mathematica, New York.
66. Station Bulletin, Purdue University.
67. Technical Reports of Research Laboratory of Electronics (M.I.T.).
68. Transactions of San Diego Society of Natural History.
69. Transactions of the American Mathematical Society.
70. Transactions of the Connecticut Academy of Arts and Sciences.
71. University of Colorado Studies; Series in Anthropology.
72. Zoologica (Scientific Contributions of New York Zoological Society).

SOUTH AMERICA

1. Anales de la Academia Nacional de Ciencias Exactas, Fisicas y Naturales de Buenos Aires.
2. Anales de la Academia de Ciencias Medicas, Fisicas y Naturales de la Habana.
3. Memorias e Estudos do Museu Zoologico da Universidade de Coimbra.
4. Memorias y Revista de la Academia Nacional de Ciencias, Mexico.
5. Publicacoes do Instituto de Botanica 'Dr. Goncalo Sampaio' da Faculdade de Ciencias de Universidade do Porto.
6. Revista Cubana de Laboratorio Clinico.
7. Trabalhos do Instituto do Botanicas 'Dr. Goncalo Sampaio' Faculdade de Ciencias da Universidade do Porto.

Trinidad—British West Indies

Tropical Agriculture (Imperial College of Agriculture).

Honolulu—Hawaii

1. Pacific Science (The University of Hawaii).
2. Bulletin of Bernice P. Bishop Museum.

EUROPE

Austria—

1. Sitzungsberichte, Wien. Abteilung 1.
2. Verhandlungen der Geologischen Bundesanstalt, Wien.
3. Zentralanstalt für Meteorologie und Geodynamik, Wien.

Belgium—

1. Bulletin du Musée Royal d'Histoire Naturelle de Belgique, Bruxelles.
2. Union Radio Scientifique Internationale, Bruxelles.

Bulgaria—

Comptes Rendus de l'Académie Bulgares des Sciences, (Mathématiques), Sofia.

Czechoslovakia—

1. Acta Facultatis Rerum Naturalium Universitatis Carolinae, Praha.
2. Memoirs de la Société Royale des Lettres et des Sciences de Bohême, Prague. Class des Sciences.
3. Publications de la Faculté des Sciences de l'Université—Masaryk, Brno.

Denmark—

1. Det Kgl. Danske Videnskabernes Selskab; Biological Skrifter.
2. Det Kgl. Danske Videnskabernes Selskab; Biological Meddelelser.
3. Det Kgl. Danske Videnskabernes Selskab; Matematiske Fysiske Meddelelser.
4. Matematisk Tidsskrift, Copenhagen.

Finland—

1. Acta Botanica Fennica, Helsingfors.
2. Acta Zoologica Fennica, Helsingfors.
3. Memoranda Societatis pro Fauna et Flora Fennica, Helsingfors.
4. Suomalaisen Tiedekatemia Toimituksia Annales Academiæ Scientiarum Fennicæ, Helsinki. Series A. Mathematica—Physica.

France—

1. Archives Internationales d'Histoire des Sciences, Nouvelle Série d'Archéon, Paris.
2. Bulletin de la Société Mathématique de France, Paris.
3. Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences, Paris.
4. La Nature, Paris.
5. U.N.E.S.C.O., Paris; Bulletin for Libraries.

6. U.N.E.S.C.O., Paris; Courier.
7. U.N.E.S.C.O., Paris; Official Bulletin.

Germany—

1. Fiat Review of German Science, Wiesbaden.
2. Schriften des Naturwissenschaftlichen Vereins für Schleswig Holstein, Kiel.

Great Britain—

1. Annals of Tropical Medicine and Parasitology, Liverpool School of Tropical Medicine.
2. Annual Report of British Non-Ferrous Metals Research Association.
3. Annual Report of the Fresh Water Biological Association of the British Empire.
4. Atomic Scientists News.
5. British Science News.
6. Bulletin of the British Non-Ferrous Metals Research Association.
7. Discovery.
8. Endeavour.
9. Fuel.
10. Geophysical Memoirs of Meteorological Office, London.
11. Journal of the Institute of Fuel.
12. Memoirs and Proceedings of the Manchester Literary and Philosophical Society.
13. Nature.
14. Philosophical Transactions of the Royal Society of London, Series A and B.
15. Physics Abstracts (Section A of Science Abstracts).
16. Plant Breeding Abstracts.
17. Proceedings of the Royal Society of Edinburgh, Sections A and B.
18. Proceedings of the Royal Society of London, Series A and B.
19. Reports of the Department of Scientific and Industrial Research of Great Britain.
20. Report of the Nuffield Foundation.
21. Report of Rothamstead Experimental Station.
22. Research.
23. Science Library Bibliographical Series of Science Museum, South Kensington.
24. Science Museum Library; Monthly List of Accessions to the Library.
25. Science Progress.
26. Today.
27. Transactions and Proceedings of the Botanical Society of Edinburgh.
28. Universities Quarterly.

Ireland—

Proceedings of the Royal Irish Academy, Dublin, Sections A and B.

Hungary—

1. Hungarica Acta Physiologica (Academia Scientiarum Hungaricae, Budapest).
2. Termeszeti és Technika, Budapest.

Italy—

1. Atti della Società Italiana di Scienze Naturali e del Museo Civico di Storia Naturale in Milano, Milan.
2. Pubblicazioni della Stazione Zoologica di Napoli.

Netherlands—

Jaarboek der Rijksuniversiteit te Leiden, Leiden.

Norway—

Bergens Museums Arbok, Bergen.

Poland—

1. Bulletin Internationale de l'Académie Polonaise des Sciences et des Lettres, Cracovie.
2. Comptes Rendus Mensuels des Séances de l'Académie des Sciences Mathématiques et Naturelles, Cracovie.
3. Fundamenta Mathematicae, Warsaw.

Roumania—

Bulletin de l' Ecole Polytechnique de Jassy, Jassy.

Sweden—

1. Bulletin Mensuel de l' Observatoire Meteorologie de l' Universitite d' Uppsala.
2. Bulletin of the Geological Institution of the University of Uppsala.
3. Chalmers Tekniska Hogskolas Handlingar (Transactions of the Chalmers University of Technology, Gotheburg).
4. K. Lantsbruks Hogskolas Annaler, Uppsala.
5. K. Svenska Vetenskapsakadamiens, Stockholm; Arkiv for Kemi, Mineralogie och Geologie.
6. K. Svenska Vetenskapsakadamiens, Stockholm; Arkiv for Matematik, Astronomi och Fysik.
7. K. Svenska Vetenskapsakadamiens Handlingar, Fjarde Serien.
8. K. Svenska Vetenskapsakadamiens Handlingar, Tredje Serien.
9. Lunds Universitets Arsskrift, New Series.

Switzerland—

1. Archives des Sciences (Societe de Physique et d' Histoire Naturelle de Geneve).
2. Verhandlungen der Naturforschenden Gesellschaft in Basel.
3. Verhandlungen der Schweizerischen Naturforschenden Gesellschaft, Bern.
4. Vierteljahrsschrift der Naturforschenden Gesellschaft in Zurich.

U.S.S.R.—

(Titles translated into English.)

1. Astronomical Journal of the Academy of Sciences of the U.S.S.R.
 2. Biochemistry Journal of the Academy of Sciences of the U.S.S.R.
 3. Modern Biological Successes.
 4. Bulletin of the Academy of Sciences of U.S.S.R., Series Biologique.
 5. Bulletin of the Academy of Sciences of U.S.S.R., Series Economics and Law.
 6. Bulletin of the Academy of Sciences of U.S.S.R., Series History and Philosophy.
 7. Bulletin of the Academy of Sciences of U.S.S.R., Series Literature and Linguistics.
 8. Bulletin of the Academy of Sciences of U.S.S.R., Series Mathematics.
 9. Doklady (Comptes Rendus of the Academy of Sciences of the U.S.S.R.).
 10. Journal of the Crimean Astrophysical Observatory.
 11. Journal of General Biology.
 12. Journal of General Physiology.
 13. Mathematical Collections.
 14. Memoirs of the Academy of Sciences of U.S.S.R.
 15. Memoirs (Bestnik) of Ancient History.
 16. Microbiology.
 17. Nature.
 18. Soviet State and Law.
 19. Zoological Journal.
-

APPENDIX

(a) Receipts and Payments Account

Receipts.	1st April 1948 to 17th Nov. 1948	18th Nov. 1948 to 31st March 1949	Total.
	Rs. A. P.	Rs. A. P.	Rs. A. P.
To Opening Balance as on 1st April 1948:—			
Rs. A. P.			
4% Loan 1960-70 F.V. Rs. 17,000			
3% Conversion Loan 1946 F.V. Rs. 29,600			
	47,189 3 10		
Imperial Bank of India Current A/c ..	46,743 15 7		
Imperial Bank of India Saving Bank Account ..	2,514 3 6		
Cash in hand ..	23 9 9		
	96,471 0 8		96,471 0 8
.. Grant from Government of India ..	58,500 0 0	98,500 0 0	1,57,000 0 0
.. Grant from Government of India for Building ..	....	50,000 0 0	50,000 0 0
.. Refund of Grant-in-Aid for Scientific Publications ..	6,000 0 0	....	6,000 0 0
.. Grant-in-Aid from Calcutta University ..	500 0 0	....	500 0 0
.. Members' Subscription ..	3,134 14 0	5,960 0 0	9,094 14 0
.. Members' Compounding Fee ..	562 0 0	....	562 0 0
.. Members' Admission Fee ..	....	480 0 0	480 0 0
.. Indian Science Abstract Fund ..	....	10,000 0 0	10,000 0 0
.. Employees' Provident Fund ..	....	1,726 10 0	1,726 10 0
.. Security from Accountant ..	....	2,000 0 0	2,000 0 0
.. I.C.I. Grant for Administration for Research Fellowship ..	26,400 0 0	13,200 0 0	39,600 0 0
.. I.C.I. for Research Fellowship Stipend ..	25,946 11 0	12,000 0 0	37,946 11 0
.. I.C.I. Research Fellowship Contingencies ..	3,242 10 0	1,500 0 0	4,742 10 0
.. Sale of Publications of the Institute ..	714 15 0	680 8 0	1,395 7 0
.. Interest Realised ..	643 4 0	668 6 0	1,311 10 0
.. Miscellaneous Receipts ..	9 0 0	38 6 9	47 6 9
.. Employees Contribution to Provident Fund ..	591 3 0	284 8 0	875 11 0
.. Income-tax Recovered ..	....	17 3 0	17 3 0
.. Dr. N. L. Phalnikar (Deceased) ..	341 7 0	....	341 7 0
.. Advance to Calcutta Office (Gross Receipts) ..	....	7,388 9 6	7,388 9 6
.. Advance to Poona Office (Gross Receipts) ..	1,351 10 3	1,378 14 9	2,730 9 0
.. Advance to Dr. S. L. Hora (Net) ..	....	150 0 0	150 0 0
TOTAL ..	2,24,408 10 11	2,05,973 2 0	4,30,381 12 11

Examined and found correct.

KASHMERE GATE, DELHI,
4th June, 1949.S. VAIDYANATH AIYAR & CO. }
Registered Accountants.

Auditors.

V

for the year ended 31st March, 1949

Payments.	1st April 1948 to 17th Nov. 1948	18th Nov. 1948 to 31st March 1949	Total.
	Rs. A. P.	Rs. A. P.	Rs. A. P.
By Salaries and Gratuity	14,951 10 6	9,607 5 0	24,558 15 6
„ Institute Contribution towards Provident Fund .. ..	.....	1,079 6 0	1,079 6 0
„ Travelling Expenses	15,289 1 9	5,561 14 6	20,851 0 3
„ N.I.S. Research Fellowship and Contingencies	37,091 1 0	28,937 10 0	66,028 11 0
„ Publications including Freight and Cartage thereon	17,701 12 0	26,884 0 0	44,585 12 0
„ Grant-in-Aid to Scientific Societies for publications .. ..	.....	15,000 0 0	15,000 0 0
„ Library Expenses	4,590 14 3	4,615 2 3	9,206 0 6
„ I.C.I. Research Fellowship Expenses:—			
Administration	4,085 2 9	2,734 4 0	6,819 6 9
Advertisement	758 8 0	528 8 0	1,287 0 0
Stipends	18,217 9 9	12,586 10 6	30,804 4 3
Contingencies	1,057 11 6	2,189 0 3	3,246 11 9
„ Expenses for Compilation of Register of Scientific Research Personnel in India	1,351 10 3	1,378 14 9	2,730 9 0
„ Expenses towards Popularisation of Science	4,000 0 0	....	4,000 0 0
„ Building Construction (Foundation Stone and Plan Expenses)	7,767 4 6	1,000 0 0	8,767 4 6
„ Provident Fund Payment to ex-Employees	2,096 5 0	588 11 0	2,685 0 0
„ Rent, Rates and Taxes	288 0 0	1,420 0 0	1,708 0 0
„ Printing and Stationery	1,456 9 0	2,431 3 0	3,887 12 0
„ Office Equipment	498 0 0	13 0 0	511 0 0
„ Postage and Telegrams	694 14 9	926 1 3	1,621 0 0
„ Advertisement	246 4 0	155 15 0	402 3 0
„ Conveyance Expenses	203 12 0	36 6 0	240 2 0
„ Miscellaneous Expenses including Servants' Liveries	354 14 0	163 15 0	518 13 0
„ Audit Fee	200 0 0	150 0 0	350 0 0
„ Bank Charges	14 0 0	169 10 6	183 10 6
„ Contribution to other Science Academies under Rule 19	36 4 0	672 0 0	708 4 0
„ Amount Recoverable from ex-Accountant .. ..	.....	351 7 3	351 7 3
„ Advance to Delhi Office Staff	795 0 3	442 1 9	352 14 6
(Cr.)			
„ Advance to Calcutta Office Staff .. ..	.....	105 0 0	105 0 0
„ Advance to Calcutta Office (Gross Payments)	3,000 0 0	4,095 0 0	7,095 0 0
„ Advance to Poona Office (Gross Payments) .. ..	.....	1,000 0 0	1,000 0 0
„ Cash and other balances:—			
4% Loan 1960-70 Face value Rs.17,000 .. ..	.....	47,189 3 10	.....
3% Conversion Loan 1946 Face value Rs.29,600 .. ..	.....		.....
Imperial Bank of India on Current Account .. ..	.....	1,17,899 15 10	.....
Imperial Bank of India on Saving Bank Account .. ..	.....	2,539 5 6	.....
Imperial Bank of India Provident Fund Saving Account .. ..	.....	1,726 10 0	.....
Cash in hand .. ..	.....	312 15 6	.....
Postage Imprest .. ..	.....	28 6 6	1,69,696 9 2
TOTAL ..	1,36,746 5 3	2,93,635 7 8	4,30,381 12 11

(b) Imperial Chemical Industries (India) Research Fellowship Grant.

	Rs.	A.	P.		Rs.	A.	P.
To Balance as on 1-4-48 ..	3,874	1	9	By Receipts during the year			
„ Payments during 1948-49	34,051	0	0	1948-49 ..	42,689	5	0
„ Balance as on 1-4-49 ..	4,764	3	3				
TOTAL ..	42,689	5	0	TOTAL ..	42,689	5	0
				By Balance as on 1-4-49 ..	4,764	3	3
				(Stipend Rs.742/6/9 and			
				Contingencies Rs.4,021/12/6).			

(c) Chandrakala Hora Memorial Medal Endowment.

[Founded from an endowment of Rs.3,000 by Dr. S. L. Hora and Mrs. V. Hora in memory of their daughter to be bestowed quinquennially on the person who has made conspicuously important contributions to the development of fisheries in India during the five years preceding the year of award.]

				By Balance as on 1-4-48 ..	3,221	15	0
				„ Interest—half-year ending			
				15-9-48 (less Income-			
				tax) ..	30	15	0
To Balance ..	3,252	14	0	TOTAL ..	3,252	14	0
TOTAL ..	3,252	14	0	By Balance as on 1-4-49 ..	3,252	14	0

(d) Grant for National Register of Scientific and Technical Personnel in India.

To Expenses during the year				By Balance as on 1-4-48 ..	1,344	15	6
1948-49 ..	2,730	9	0	„ Balance ..	1,385	9	6
TOTAL ..	2,730	9	0	TOTAL ..	2,730	9	0
To Balance as on 1-4-49 ..	1,385	9	6				

(e) Popularization of Science Fund.

To Payments during 1948-49	4,000	0	0	By Receipts up to 1-4-48 ..	4,402	0	0
„ Balance ..	402	0	0				
TOTAL ..	4,402	0	0	TOTAL ..	4,402	0	0
				By Balance as on 1-4-49 ..	402	0	0

APPENDIX

Budget Estimates for 1950-51 together with
RECEIPTS

				I—GOVERNMENT		
				1948-49 (Actuals)	1949-50 (Revised Estimates)	1950-51 (Estimates)
				Rs.	Rs.	Rs.
Government Grant	..	..		1,78,582 (including Rs. 21,582 carried over from pre- vious year)	1,77,000 + 33,000 (Addi- tional requested for) + 2,394 (For registration)	2,15,625
TOTAL				1,78,582	2,12,394	2,15,625
II—I.C.I. (INDIA) RESEARCH						
1. Stipends	..	..		37,947	54,444	64,700
2. Contingencies for Research Fellows	..	..		4,743	6,343	8,100
3. Administration	..	..	(for 3 years)	39,600	13,200	13,200
TOTAL				82,290	73,987	86,000
III—GENERAL						
1. Admission Fee	..	..		480	448	480
2. Compounding Fee	..	..		562	1,133	500
3. Membership Subscriptions	..	..		9,095	6,272	6,320
4. Contributions—Calcutta Univer- sity	..	..		500	500	500
5. Interest on Investments	..	..		1,312	1,984	1,600
6. Sale of Publications	..	..		1,395	1,506	1,500
7. Miscellaneous	..	..		47	90	100
8. Transfer from Indian Science Abstracts Fund	..	..		..	..	15,000
TOTAL				13,391	11,933	26,000
GRAND TOTAL				2,74,263	2,98,314	3,27,625

VI

Revised Estimates for 1949-50 and actuals for 1948-49.

EXPENDITURE

GRANT-IN-AID

	1948-49 (Actuals)	1949-50 (Revised Estimates)	1950-51 (Estimates)
	Rs.	Rs.	Rs.
1. Staff (including allowances and Provident Fund)	25,638	25,000	25,000
2. T.A.	20,851	20,000	20,000
3. N.I.S. Research Fellowships	66,029	1,20,000	1,20,000
4. Library	9,206	10,000	10,000
5. Publications—			
(a) Institute	44,586	20,000	20,000
(b) Other Societies	15,000	15,000	15,000
6. Land for Institute Building:—			
(a) Registration of Lease Agreement .. .. .	..	2,394	..
(b) Rent .. .. .	..	..	5,625
TOTAL ..	1,81,310	2,12,394	2,15,625

FELLOWSHIPS

1. Stipends	30,804	54,444	64,700
2. Contingencies for Research Fellows	3,247	6,343	8,100
3. Administration	8,106	13,200	13,200
TOTAL ..	42,157	73,987	86,000

FUND

1. Investment Account (Admission and Compounding Fees: Chandrakala Hora Memorial) .. .. .	..	1,671	1,070
2. Contribution to Indian Standards Institution .. .. .	..	250	250
3. Transfer to Co-operating Academies	708	360	360
4. Printing and Stationery	3,888	4,550	4,160
5. Rents, Rates and Taxes	1,708	1,000	1,000
6. Advertisements	402	400	460
7. Postage and Telegrams	1,621	1,900	1,950
8. Conveyance	240	200	200
9. Office Equipment	511	500	500
10. Audit Fee	350	300	250
11. Bank Charges	184	190	200
12. Miscellaneous	519	612	600
13. Publication of—			
(i) Progress of Science in India (in place of Indian Science Abstracts)	..	..	15,000
(ii) Year Book			
TOTAL ..	10,131	11,933	26,000

GRAND TOTAL ..	2,33,508	2,98,314	3,27,625
-----------------------	-----------------	-----------------	-----------------

APPENDIX VII

SUMMARIES OF RESEARCH REPORTS OF RESEARCH FELLOWS

A. NATIONAL INSTITUTE OF SCIENCES SENIOR RESEARCH FELLOWSHIP.

(a) ANNUAL REPORT.

Name of Research Fellow .. Dr. J. Bhimasenachar.
 Subject of Research .. Elastic Properties of Polycrystals.

(September, 1948—September, 1949.)

During the year under review, employing the Wedge Method developed in these Laboratories, the Elastic Constants of single crystals of corundum, a very important mineral, have been determined. A preliminary note on these results has been published in the pages of *Current Science* and a detailed report has been submitted to the Institute for favour of publication. Results on measurements of the Elastic Constants of single crystals of Zircon which have been completed, are being submitted for favour of publication.

In collaboration with Mr. T. Seahagiri Rao, Physics Department, Andhra University, Elastic Constants of Some Cubic Nitrates (the series of barium, strontium and lead nitrates crystallising in the cubic system) have been determined by the Wedge Method. The results have been submitted to the Institute for favour of publication. In collaboration with the same worker Ultrasonic Velocities in Mineral Acids have been determined using a specially designed crystal holder (a preliminary report of these results has been published in *Current Science*).

In all the measurements reported above the variable frequency R.F. oscillator worked in the range of 1 to 10 M/Cs. and had an R.F. power output of about 10 Watts. With this outfit attempts were made to determine the Elastic behaviour of quartzite which usually consists of small crystals of quartz in a base of amorphous silica. From a lump of quartzite available in this laboratory plates were cut in two mutually perpendicular directions and velocities of transmission of ultrasonic waves were determined by the Wedge Method. It was found that the transmission of the ultrasonic waves was very weak with the result only transmission of longitudinal waves was observed whereas the transmission of torsional waves was not observed. Under these conditions no relation could be obtained between the elastic behaviour of the quartzite plate and the elastic constants of the single crystals of quartz and the elastic constant of silica.

It was felt that a more powerful variable frequency R.F. oscillator would be helpful in the investigations. Accordingly an oscillator has been designed to give ultimately an R.F. power of 500 watts in the region of 1 to 200 M/Cs. The necessary power supply unit has been rigged up and it is capable of delivering 750 m.a., at 2,500 volts with a ripple less than 1%. As a first step in the completion of this powerful unit a variable frequency R.F. oscillator working in the region of 2 to 40 M/Cs. and giving 200 watts of R.F. power has been constructed using a single Philips T.B. 2.5/300 valve.

With this powerful set the elastic behaviour of quartzite will be investigated again. A series of experiments on compressed crystal powder cakes of barium nitrate will be undertaken.

(b) FINAL REPORT.

Name of Research Fellow .. Dr. F. C. Auluck.
 Subject of Research .. Statistical Thermodynamics and Quantum Electrodynamics.

(February, 1947—August, 1948.)

The research work was done mainly along two lines:—

(i) *Partition Theory and Statistical Thermodynamics.*

The first physical application of the partition theory [the celebrated formula due to Hardy and Ramanujan for $p(n)$] was made by Bohr and Kalckar in 1937 in estimating the density of energy levels for a heavy atomic nucleus. A detailed study of the correspondence between Statistical Thermodynamics and the Theory of partition of numbers has been made. This study has led to several interesting generalizations of the partition concept, an important result being the extension of the idea of partition to non-integral

powers of integers. For example there are only 15 numbers less than or equal to 4, which can be expressed as the sum of the square roots of integers.

(ii) *Quantum electrodynamics.*

Beginning with Dirac's fundamental paper of 1938 on the classical theory of the electron, the subject of quantum electrodynamics is at present in the forefront of physical interest. The Riesz method which had proved so fruitful in the study of hyperbolic equations (Huygen's principle and related problems) provides a powerful technique for dealing with divergent difficulties in electrodynamics and meson theories. We have made a study of this method and obtained some new and interesting results, e.g. we have shown the equivalence of this method with the method of residues. In another paper a Fourier analysis of the Riesz field has been made and applied to the elimination of the longitudinal waves. This subject has at the moment become of exceptional importance in view of the discrepancy between Dirac's theory and the spectrum of the hydrogen atom established by the beautiful experiment of Lamb and Rutherford.

Some of the results obtained have already been published in the following papers, and others are under publication:—

1. Partitions into powers of integers (with Dr. D. S. Kothari). *Proc. Roy. Irish Acad.*, April 14, 1947, p. 13.

This paper deals with the partitions of a large number n into summands each of which is the s th power of some positive integer, s being a positive integer, repetitions being or not being allowed.

2. Partitions into non-integral powers of n (with Dr. D. S. Kothari). *Nature*, **162**, 1948, 143.
3. Partitions of numbers into non-integral powers of integers (with B. K. Agarwala) under publication.
4. On New Partition Formulae.
(With K. S. Singwi and B. K. Agarwala) (under preparation).

This paper deals with the number of partitions of a large integer n into smaller integers and half odd integers, such that each summand is either not repeated at all or is allowed to repeat only an odd number of times and (i) in each partition the 'types' of summands is exactly N , and (ii) when there is no restriction on the number of 'types'.

5. Electromagnetic level shift and effect on radiation field (with D. S. Kothari). *Nature*, July, 1948.
6. A note on the Riesz method and the method of residues (with D. S. Kothari). *Proc. Roy. Soc.*, **198**, 1949, 170.
7. Thompson scattering and the hole theory (with D. S. Kothari). *Phys. Rev.*, **76**, 1949, 433.
8. Riesz field and its Fourier Analysis (under publication).

Name of Research Fellow .. Dr. B. D. Tilak.

Subject of Research .. Affinity of Dyes for Cellulose and Proteins.

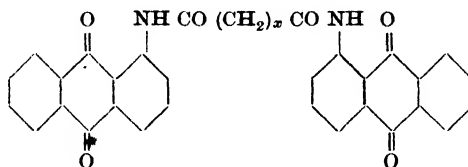
(August 23—November 7, 1948.)

While the addition of surface active agents in the dyeing process generally leads to level shades it is not clear whether surface activity in a dye molecule will lead to better substantivity and better fastness properties. With a view to study the relationship between surface activity and substantivity in the azoic dyes, fatty acid derivatives of 2-hydroxy-3-naphthoic-(4-amino) anilide were prepared by condensing two molecules of the latter compound with adipic and sebacic acid dichlorides. The corresponding lauric acid derivative was also prepared. The azoic dyeings from these fatty acid derivatives are being critically compared with those from Naphthol-AS (2-hydroxy-3-naphthoic anilide).

While the substantivity of several arylides of 2-hydroxy-3-naphthoic acid with different aromatic amines has been studied, the effect of substitution in the nucleus of the 2-hydroxy-3-naphthoic acid half of the molecule does not appear to have been examined. 6-Benzoyl-2-hydroxy-3-naphthoic anilide was, therefore, prepared starting from Naphthol-AS and benzodichloride. This method could also be probably extended for the preparation of other 6-aryl substituted naphthols. Substitution by benzoyl group in the 6-position in Naphthol-AS resulted in a decrease in solubility in aqueous caustic soda, and the naphtholation of the 6-benzoyl

derivative had to be carried out from an aqueous-alcoholic solution, with resultant loss in substantivity for cotton.

The substantivity of dyes for cellulose being largely governed by the ability of the dye to attach itself to cellulose by hydrogen bonding at the primary hydroxyl groups in cellulose which are spaced at regular intervals of $10\cdot3\text{\AA}$, synthesis of the fatty acid amides of the type (I) was undertaken.



(I)

$x = 0, 1, 2, 4 \text{ and } 8.$

The diamides from adipic acid ($x = 4$) and sebacic acid ($x = 8$) were synthesised by condensing the corresponding acid dichlorides and α -aminoanthraquinone. The oxalic acid ($x = 0$) diamide was a yellow sparingly soluble vat dye.

Name of Research Fellow .. Dr. K. Subba Rao.

Subject of Research .. Colloids.

Drought Resistance of plants in relation to Hysteresis in Sorption I.

Hydration and dehydration of the leaves of certain drought resistant and drought sensitive plants.

A new approach to the problem of drought resistance of plants has been made from the point of view of Hysteresis in Sorption (Rao, K. S., Rao, M. B. and Rao, B. S., *Curr. Sci.*, 334, 17, 1948; *Proc. Nat. Inst. Sci. (India)*, 15, pp. 41-49, 1949). Balsam, Grass, Paddy, Ragi, Wheat and Oats were chosen for the study. The leaves of these plants were subjected to successive dehydration and hydration in a quartz fibre spring balance (McBain, J. W. and Bakr., *J. Am. Chem. Soc.*, 690, 48, 1926; Rao, K. S., *J. Phys. Chem.*, 500, 45, 1941).

Hysteresis effect is observed in all the systems and the hysteresis loop disappears after a certain number of hydrations and dehydrations. In the early stages, the capillaries of the leaf are made up of fairly rigid walls. The cavities entrap water and cause hysteresis. The entrapping effect is due to the rigidity of the leaf tissue. It is likely that the rigidity of the leaf tissue is a factor of importance in enabling the plants to conserve water during periods of drought.

On successive hydration and dehydration of the leaf, there is a fall in the hydration capacity at saturation pressure. This is due to the denaturation of the protoplasm and a decrease in the hydrophilic character.

The relative positions of the hydration isotherms of the leaves indicate that in the relative humidity range of 0.5-0.95, the six plants show a gradation in the water holding capacity. At any particular humidity in this range, balsam takes the lowest and oats the highest amount of water. The six plants can be arranged in the increasing order of drought resistance as follows:-- balsam, grass, paddy, ragi, wheat and oats. Balsam is the least and oats the most drought resistant. In accordance with the cavity theory of sorption hysteresis (Rao, K. S., *Curr. Sci.*, 69, 9, 1940), there is in balsam a preponderance of wider cavities and in oats of narrower ones.

Drought Resistance of plants in relation to Hysteresis in Sorption II.

Adaptability of the Ragi plant to varying conditions of soil drought.

The principle of adaptability of drought sensitive plants to severe drought conditions is one of great importance and has been extensively studied by Russian workers. Whether during this adaptation, any change is produced in the capillary structure of the leaf has been studied with reference to ragi as the experimental plant (Rao, K. S., Rao, M. B. and Rao, B. S., *Proc. Nat. Inst. Sci. (India)*, 15, pp. 51-58, 1949). Ragi plants A, B, C and D were grown in soil droughts of 65%, 47%, 40% and 36.5% respectively of the total water holding capacity (26%) of the red laterite soil. There was a marked difference in the growth, height and yield of the four plants.

When the plants were 80 days old, the blades were removed and subjected to a series of dehydration and hydration at 30°C . in a quartz fibre spring balance. Hysteresis is exhibited in all the cases. The hydration and dehydration isotherms and the hysteresis loops are nearly

coincident. This indicates that the cavities and open pores in the blades of the four plants are almost of the same size.

There is, however, a regular variation, though small, in the smallest cavity neck radius. The radius in D is smaller than that in A, those in B and C being intermediate between these two. It is probable that by extending the treatment of exposure of the plant to severe drought over a number of generations, the small differences in the capillary structure of the leaves may become more prominent.

The amount of water lost in the initial dehydration of the leaves is related to the age of the plant. The leaves of 80-day old plants lost approximately 350 gms. of water per 100 gms. of dry leaf whereas those of 120-day old plants lost 255 gms.

Changes in pH of the white and yolk of fertilised hen's egg during incubation in air, carbon dioxide and liquid paraffin.

The variation in pH is an important factor in the elucidation of the mechanism of many biochemical processes. The variation in pH of the white and yolk of fertilised hen's egg during incubation in air, carbon dioxide and liquid paraffin has been studied. After incubation over different intervals of time, the eggs were removed, the white and yolk were separated and the pH determined by employing a glass electrode. In fresh egg, the white has a pH of 7.85 and the yolk 6.17. On continued incubation in air, the pH of white increases to a maximum of 9.5 up to 36 hours and later decreases continuously. The pH of the yolk is practically constant up to the 2nd day and later increases slowly but continuously. The initial rise in pH of the white is due to the loss of carbon dioxide and the subsequent fall to the metabolic processes resulting in the production of carbon dioxide. The small increase in pH of the yolk is due to protein catabolism resulting in the formation of ammonia (Needham, J., 1942, *Biochemistry and Morphogenesis*, Macmillan Co., New York, p. 592).

The pH-Time curves of the white and yolk of eggs incubated in carbon dioxide and liquid paraffin are practically coincident. The pH of the white shows a small and continuous decrease and that of the yolk a small and continuous increase. The conditions being anaerobic, the normal metabolic processes in the growing embryo are hindered. Consequently the changes in pH are small.

Hysteresis in Sorption XVII.

Hardening of sericin and its influence on sorption-desorption hysteresis.

The behaviour of sericin in regard to the hysteresis effect in the sorption of water and the effect on hysteresis of hardening sericin by hardening agents like formaldehyde and basic chromium sulphate have been studied. The hardened as well as unhardened sericin were subjected to successive sorption and desorption at 30°C. With hardened sericin, a permanent hysteresis loop is obtained whereas with unhardened sericin the hysteresis loop initially exhibited decreases in size and finally disappears.

A permanent and reproducible hysteresis loop is characteristic of a rigid gel (Rao, K. S., *J. Phys. Chem.*, 500, **45**, 1941), whereas a dwindling and disappearing loop is characteristic of an elastic gel with solvating liquids. Sericin is an elastic gel like casein, egg albumen and gelatin (Rao, G. N., Rao, K. S. and Rao, B. S., *Proc. Ind. Acad. Sci.*, 221, **25**, 1947), rice grain (Rao, K. S., *Curr. Sci.*, 256, **8**, 1939) and gum arabic (Rao, K. S., *Curr. Sci.*, 19, **9**, 1940) in losing the hysteresis loop initially exhibited in the sorption of water. On hardening, sericin loses its swelling property and behaves like a rigid gel. The cavities entrap water during dehydration and cause hysteresis. The entrapping effect persists even in the subsequent cycles of hydration and dehydration.

Compression-expansion hysteresis in surface films.

By employing the Adam's modification (Adam, *Physics and Chemistry of Surfaces*, Oxford University Press, 1941) of Langmuir surface pressure balance (Langmuir, *J. Am. Chem. Soc.*, 1848, **39**, 1917), the compression-expansion hysteresis of the films of sericin and egg albumen has been studied. The expansion curve is always below the compression curve, and the hysteresis loop is reproducible. The loop has been scanned by subjecting the film to expansion at different points on the compression curve and to compression at different points on the expansion curve. The expansion scanning curves reach the low pressure end of the loop and the compression scanning curves reach the high pressure end. The compression-expansion hysteresis effect and the characteristics of the scanning curves are probably connected with the hydration changes in the protein film.

Name of Research Fellow . . . Mr. U. R. Burman.

Subject of Research . . . Internal Constitution of Stars.

(October 1, 1948—September 30, 1949.)

The writer is engaged in the construction of convective radiative stellar models with a discontinuous change of chemical composition across the interface. The usual models in the theory of stellar structure are, however, constructed on the basis of a uniform composition throughout the whole mass, as it is not improbable that slow convection currents maintained by radiation in the domain of radiative equilibrium cause an exchange of matter between this region and the central core. There is also another point of view. According to the modern theory of energy generation in stellar interiors, continual conversion of hydrogen into helium is taking place by thermo-nuclear reactions within the convective core and the heat evolved in these processes is responsible for the maintenance of the stellar radiation. If we assume that mixing of matter does not proceed across the boundary of the core, these nuclear processes probably cause changes (increase) of molecular weight in the central part of the star while the molecular weight outside the core remains practically unaffected. This possibility may lead the star in the course of evolution to assume a structure of a new type—the model with a discontinuity of molecular weight across the surface of the convective core. A study of this latter type of model appears therefore to have considerable significance in the way of understanding the internal constitution of stars.

In a recent paper (*Proc. Nat. Inst. Sci. India*, **15**, 269, 1949) the writer has shown that if there exists a convective core fitting on to a given radiative envelope constructed by an integration of the stellar equations from the boundary inwards, with assumed values of the mass (M), radius (R) and luminosity (L) and an assigned composition constant throughout the stellar material, it is not possible to obtain another core consistent with the same envelope solution, allowing for a discontinuous change of composition across the interface. This conclusion would lend a uniqueness to the solution of the stellar problem of fit obtained under suitable circumstances.

Assuming that stars are built on this model, the writer is now working on the problem of determination of the hydrogen and helium contents of some stars from the observed values of their mass, radius and luminosity, so as to be in agreement with Bethe's law of energy generation. It has been found that the equations governing the problem, taken along with some very plausible assumptions regarding the composition of the stellar material within and outside the convective core, are just sufficient for the determination of the desired quantities. This does not, however, imply that the equations will always admit of physically significant solutions. In fact, only under very special circumstances such significant solutions are to be expected. The internal constitution of some well-known main sequence stars has previously been worked out by N. R. Sen and the present writer on the basis of uniform composition and Bethe's law, and it has been found that there are some stars whose constitution could not be explained on this model (uniform composition). The present work of the writer, as stated above, is an attempt to explain the structure of these stars, on the new model. The work involves considerable numerical computations and is expected to be completed soon, when the results will be sent for publication in the *Proceedings* of the National Institute of Sciences of India.

B. NATIONAL INSTITUTE OF SCIENCES JUNIOR RESEARCH FELLOWSHIP.

(a) ANNUAL REPORT.

Name of Research Fellow . . Mr. K. Das Gupta.
Subject of Research . . Soft X-ray spectroscopic study of solids.

(August 23, 1948—August 22, 1949.)

Energy states of valence electrons of binary ferrous alloys have been investigated with a vacuum spectrograph designed in Prof. Siegbahn's laboratory at Uppsala. The mounting is of Rowland's type and bent gypsum and mica crystal being used as concave grating to work in the soft X-ray region 5–18 A.U. K valence band spectra corresponding to the transition of valence electrons into the inner vacant K level of Al and Si of Al-Fe (21%, 35%, 65% of Al) and Si-Fe (4%, 14%, 24%, 58%, 75% of Si) alloys have been studied. $L_{\alpha_{1,2}}$ band of iron in various iron compounds have been investigated with a bent mica crystal in the region 17–18 A.U. Some special technique regarding the experimental procedure had to be adopted to investigate the L bands with its associated weak structures.

Energy states of valence electrons of NaCl have been completely drawn from the K absorption and K valence band emission spectra of Na and Cl in NaCl. The diagram indicates the origin of the fundamental ultraviolet absorption bands of NaCl as obtained by Hilsch and Pohl. Such

agreement between the experimentally observed values of ultraviolet absorption bands and those obtained indirectly from soft X-ray absorption and emission data has been obtained in the case of NaF, NaCl, NaBr, NaI, KCl, RbCl, CsCl, CaCl₂, SrCl₂, CuCl, AgCl, etc.

In the *L* band spectra of iron, the main band due to the transition $M_{IV,V} - L_{III}$ known as L_{α} appears at 17,572 for pure iron and stalloy and for compounds and alloys of iron the band shifts to shorter wavelength side and the value of λ is 17,565 x.u. In the case of alloys and compounds of iron which are less ferromagnetic or non-magnetic an extra band on the shorter wavelength side at 17,486 x.u. attributable to the 3d band structure has been obtained. The experimental results show that the energy gap between the two 3d structures is 3.0 e.v. The extra band is very weak in the case of highly ferromagnetic substances, e.g. pure iron, stalloy, Fe₃O₄, etc., and prominent in the case of Fe-Si (Si 58%), Fe-Cu (Cu 85%), Fe-Al (21% Al) in which magnetism has been considerably quenched by alloying. In the case of magnetic iron sulphide the extra band is stronger compared to that of the non-magnetic variety; similar is the case with magnetic and the non-magnetic iron oxide. The experimental results have been interpreted in the way of Pauling's semi-empirical theory of Ferromagnetism.

In the case of Al-Fe and Si-Fe alloys the K_{β} band of Al and Si shows distinct structures and the energy gap between the structures is 3.0 e.v. the same as between the 3d band structures of Fe *L* band. Such cross transition from adjacent elements apparently against the selection principle has been supposed to occur in the case of halides and the oxides and has been obtained by Skinner and the author.

Name of Research Fellow . . Mr. S. D. Misra.

Subject of Research . . Study of phases of desert locust with special reference to its musculature.

(September 16, 1948—September 15, 1949.)

1. INTRODUCTION.

The National Institute of Sciences of India granted a Junior Research Fellowship to Mr. S. D. Misra for two years (1948-50) to continue his research work on the 'Study of the Phases of the Desert Locust with special reference to its musculature', under the guidance of Prof. K. N. Bahl. The approved research work was started on September 16, 48.

2. PROGRAMME.

The study of the head (Misra, 1946), neck and prothorax (Misra, 1947) of the Desert Locust, *Schistocerca gregaria* Forskål, phase *gregaria*, having been completed earlier, the work was continued on the following lines:—

I. In phase *gregaria*,

- (i) Study of the meso- and metathorax.
- (ii) Comparison of muscles of the Desert Locust with those of other locusts and grasshoppers.
- (iii) Study of the abdomen.

II. In phase *solitaria*,

- (i) Collection of phase *solitaria* material from different places in the Rajputana desert.
- (ii) A critical and comparative study of phase *solitaria* similar to that already done in the phase *gregaria*, with a view to find out the differences in the muscles of the two phases.

3. WORK DONE DURING THE YEAR.

I. In phase *gregaria*,

- (i) A critical and complete study of the external morphology and myology of meso- and metathorax has been completed.
- (ii) A comparison of head, neck and thoracic muscles of the Desert Locust, phase *gregaria*, has been made with the following 3 locusts and a grasshopper from among the Acrididae worked out by previous workers:

Subfamily—*Catantopinae*

Schistocerca gregaria Forskål (Misra, 1946, 1947 and 1949—in *press*).
Anacridium aegyptium Linn. (Berlese, 1909, La Greca, 1947).

Subfamily—*Oedipodinae*

Dissosteira carolina Linn. (Snodgrass, 1928, 1929).

Locusta migratoria R. and F. (Imms, 1939, Uvarov and Thomas, 1942).

Subfamily—*Tryxalinae*

Doclostaurus maroccanus Thnbg. (Jannone, 1940).

Some specimens of the Egyptian Bird Locust, *Anacridium aegyptium* Linn. and the Moroccan Locust, *Doclostaurus maroccanus* Thnbg. were obtained from Italy through the courtesy of Prof. Giuseppe Jannone, Director Osservatorio Malattie, Genova. This material proved helpful in the verification of points of origin and insertion of some muscles described by Jannone (1940) and in their comparison with those of *Schistocerca gregaria*.

II. In phase *solitaria*,

(i) In order to collect phase *solitaria* material Dr. H. S. Pruthi, Plant Protection Adviser to the Govt. of India was requested to arrange for Mr. Misra's going out on a tour with a locust party, to the outbreak centres in the Rajputana desert. This tour was arranged and it enabled him to collect phase *solitaria* material as well as to see the ecological conditions prevailing in an outbreak area, *Kakoo*, in the Bikaner State in June 1949. Here, with the Anti-locust party, he learnt the method of controlling locusts by hand-picking, a method tried at the instance of the Ministry of Food, Govt. of India. He also visited Jodhpur, Nokha (Bikaner State) and Bikaner.

4. PUBLICATION.

Mr. Misra has now completed the writing out of the results of his study of meso- and meta-thorax of the Desert Locust (1 (i) in the Programme) in the form of a paper—STUDIES ON THE SOMATIC MUSCULATURE OF THE DESERT LOCUST, *SCHISTOCERCA GREGARIA* (FORSKÅL), PHASE *GREGARIA*. Part 3—The Pterothorax. This paper, with the permission of the Secretary, N.I.S., has been sent to the *Indian Journal of Entomology*, and has been accepted for publication in the December issue of that journal.

5. WORK TO BE DONE.

The work to be done during the following year is as follows:—

I. In phase *gregaria*,

- (ii) Comparison of abdominal muscles of the Desert Locust, phase *gregaria*, with those of other locusts and grasshoppers.
- (iii) Study of the morphology and myology of the abdomen.

II. In phase *solitaria*,

- (i) Taking biometrical measurements of phase *solitaria* in order to separate out the extreme forms of this phase so that the comparative study on them with those of phase *gregaria* may show the greatest contrast in the two phases.
- (ii) The comparative study of phase *solitaria* with that of the *gregaria*.

Name of Research Fellow . . . Mr. Y. Sunder Rao.

Subject of Research . . . Cytology of Helobiales.

(October 18, 1948—October 19, 1949.)

Mr. Y. Sundar Rao has been engaged during the year 1948-49 in the cytological study of Helobiales, an order of great importance from the view point of phylogeny of the following plants, particularly monocotyledons. He has investigated the families Butomaceae, Alismaceae, Hydrocharitaceae and Najadaceae, giving special attention to the comparison of the karyotypes in order to elucidate intergeneric and interspecific relationships and work out the genetic basis of evolution in the group.

BUTOMACEAE.

Butomopsis lanceolata Kunth. The 14 somatic chromosomes (two long, four medium and one short pairs) are characterised by median, submedian and terminal constrictions. The

presence of three pairs of chromosomes with terminal constrictions is the striking feature of the karyotypes.

Hydrocleis commersonii (-*nymphoides*) Rich. The diploid chromosome complement with about 12 chromosomes is similar to that of *Butomopsis* indicating a close relationship and common origin.

Butomus umbellatus Linn. This genus is interesting for its diploid, aneuploid and triploid intraspecific chromosome races with 26, 28 and 40 chromosomes respectively; the race with 26 chromosomes is a common one in India, Sweden and America. It is interesting to note that the basic number 13 can be derived from 7 and 6 of the two previous genera. Hybridisation and subsequent amphidiploidy are the probable factors of evolution of this genus.

ALISMACEAE.

Alisma plantago Linn. This is a diploid species of *Alisma* with 14 chromosomes out of which two are satellited. There are five pairs of chromosomes with median or submedian constrictions and two pairs with subterminal or terminal constrictions.

Echinodorus Rich. Two species were studied: *E. ranunculoides* with $2n = 16$ and *E. radicans* with $2n = 22$. The former has four pairs of median or submedian chromosomes and four pairs of terminal or subterminal chromosomes. The latter has all the chromosomes with either terminal or subterminal constrictions except one long pair with median constrictions.

Sagittaria sagittifolia Linn. The diploid number is 22. In having one long pair with median constrictions and the rest with subterminal constrictions, the karyotype of this genus resembles that of *Echinodorus radicans*.

HYDROCHARITACEAE.

In this family the following are the diploid chromosome numbers: *Blyxa* sp., $2n = 16$; *Hydrilla verticillata* Casp., $2n = 16$; *Vallisneria spiralis* Linn., $2n = 20$; *Ottelia alismoides* Pers., $2n = 22$, *Ca* 40 and 66 and *Boottia* sp., $2n = 66$.

In *Vallisneria*, there are three pairs of long, one pair of medium and six pairs of short chromosomes with terminal or subterminal constrictions and with no sex chromosome mechanism. *Blyxa* sp., though similar to *Vallisneria* in vegetative characters, has a different karyotype. The 16 chromosomes have either terminal or subterminal constrictions. In *Hydrilla verticillata*, the five pairs of long and the three pairs of short chromosomes are characterised by median, submedian and subterminal constrictions. The genus *Ottelia*, particularly the species *O. alismoides*, is interesting for its diploid, tetraploid and hexaploid chromosome races with different ranges of geographic distribution. *Boottia* sp. agrees with hexaploid *Ottelia* in chromosome numbers, in spite of its decline.

NAJADACEAE.

One tetraploid species of *Najas* with 24 chromosomes with a pair of SAT-chromosomes has been studied.

GENERAL CONCLUSIONS.

The pattern of evolution of genera and species in Helobiales seems to be governed by (1) *aneuploidy*, which determines the intergeneric relationships in many families; (2) *polyploidy*, either by simple multiplication of whole chromosome sets or by the fusion of diploid and haploid gametes leading to the formation of a series of intraspecific polyploid races ranging from triploids to hexaploids, which differ little in morphological features, but have their own range of geographic distribution; (3) *amphidiploidy*, which is responsible for the evolution of higher taxonomic units, like the genus *Butomus*; (4) *structural changes* like fragmentation and reciprocal translocations or inversions, leading to the formation of terminally or subterminally constricted chromosomes, which form an outstanding feature of the karyotypes encountered in most of the genera. Such changes are usually associated with aneuploidy or polyploidy; (5) *mutational or amphiplastic loss of satellites*.

Name of Research Fellow .. Mr. V. R. Thiruvengkatachar.
Subject of Research .. Studies in compressible fluid flow.

(December 19, 1947—December 18, 1948)

The general subject of the research undertaken concerns recent developments in the theory of compressible fluid flow; in particular, the hodograph method, subsonic and supersonic flow past given bodies such as a cylinder or airfoil, the occurrence of limiting lines and phenomena relating to shock waves.

The following special problems have been investigated:—

1. *Analogue of Blasius' formulae in subsonic compressible flow.*

A generalisation of the von Kármán-Tsien method was given recently by C. C. Lin for obtaining compressible flows with circulation around closed profiles. Starting from the equations given by Lin, the following formulae may be derived for the force (F) and the moment (M) in subsonic compressible flow, which are analogous to the classical formulae of Blasius:

$$\bar{F} = \frac{1}{2} \rho_0 \oint \frac{w_0^2(\xi)}{k(\xi)} d\xi$$

$$M = Re \left\{ -\frac{1}{2} \rho_0 \oint \frac{w_0^2(\xi)}{k(\xi)} z d\xi \right\}$$

Here $w_0(\xi)$ is the complex velocity in the associated incompressible flow and $k(\xi)$ is the function introduced by Lin. It is further shown that when applied to a simple airwing in a uniform stream, the force-formula yields the Prandtl-Glauert rule. These results are given in a paper published in the *Proc. Nat. Inst. Sci.*, XIV, No. 8, 1948.

2. *Thin airfoil in compressible shear flow.*

The problem of shear flow past a circular cylinder and a symmetric airfoil has been worked out by H. S. Tsien in the case of a perfect fluid. An attempt has been made to investigate if the notion of shear flow could also be used in the case of compressible fluids. Helmholtz's vorticity theorem, when applied to 2-dimensional steady flow, yields the following condition for compressible shear flow:

$$v_x - u_y = -\frac{kU}{\rho_0} \rho$$

where $u_0 = U(1 + ky)$, $v_0 = 0$ is the velocity and ρ_0 the density in the main stream. With this condition, the problem of a thin wing in compressible shear flow has been worked out and expressions for the drag and the lift have been derived. It is first shown that the flow problem can be reduced to one for a potential flow with velocity-potential ϕ and stream function ψ , satisfying the differential equations

$$\{1 - M^2(1 + ky)^2\} \phi_{xx} + \phi_{yy} = 0 \quad \dots \quad (A)$$

$$\phi_{xx} + \frac{\partial}{\partial y} \left\{ \frac{\psi_y}{1 - M^2(1 + ky)^2} \right\} = 0 \quad \dots \quad (B)$$

By suitable approximations, the equation (B) is reduced to the following form, in the case $M > 1$:

$$\psi_{xx} - \psi_{\xi\xi} + \lambda \psi_{\xi} = 0$$

where λ is a constant. A solution of this equation satisfying the boundary conditions (expressed in terms of ψ) is constructed by means of the Fourier integral and thence expressions for the drag and the lift are derived which are analogous to those in the shear-free case. A paper embodying these results has been published in the *Proc. Nat. Inst. Sci.* (Vol. XV, 1949).

An alternative method of procedure has also been devised, which consists in starting out with the equation (A) instead of (B). The boundary condition (expressed in terms of ϕ now) is developed into a Fourier series and the equation (A) is solved by the usual method of separation of variables. This method is applicable in both the subsonic and supersonic cases.

3. The problem mentioned in No. 2 above is that of a thin airfoil in *steady* shear flow. The corresponding problem of the *nonsteady* motion of a thin airfoil in shear flow has also been studied, on the lines of the work of O. Taussky in the case of *uniform* supersonic flow. The following formula for the velocity potential is derived:

$$\phi(\xi, \eta, \tau) = -\frac{e^{-m\eta}}{\pi} \iint_H \left(\frac{\partial \phi}{\partial \xi} + m\phi \right) V ds$$

where $V = e^{\frac{m\xi}{\sqrt{\Gamma}}} \cdot \frac{\cos(m\sqrt{\Gamma})}{\sqrt{\Gamma}}$, $\Gamma = (t-\tau)^2 - [x-\xi - M(t-\tau)]^2 - (\xi-\eta)^2$.

For the shear-free case this reduces to the formula of Taussky. (*Proc. Nat. Inst. Sci.*, XV, 1949.)

4. Circular cylinder is compressible shear flow.

With the notion of compressible shear flow introduced above, the problem of the flow past a circular cylinder has been investigated. The corresponding problem in the incompressible case has been treated by Tsien. For the solution of our problem, use has been made of the Chaplygin-Kármán-Tsien approximation and the Rayleigh-Janzen expansion. The equations of motion and the condition for compressible shear flow yield the following differential equation for the stream function:

$$\frac{\partial}{\partial x} \left(\frac{\rho_0}{\rho} \frac{\partial \psi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{\rho_0}{\rho} \frac{\partial \psi}{\partial y} \right) = kU \frac{\rho}{\rho_0}. \quad \dots \dots \dots (C)$$

With the Chaplygin-Kármán-Tsien approximation, the Bernoulli equation for this case gives

$$\left(\frac{\partial \psi}{\partial x} \right)^2 + \left(\frac{\partial \psi}{\partial y} \right)^2 - c_0^2 = \left(2kU\psi + U^2 - c_0^2 \right) \frac{\rho^2}{\rho_0^2}, \quad \dots \dots \dots (D)$$

where c_0 = acoustic velocity at infinity. The equations (C), (D) constitute two equations for determining ψ and ρ .

We solve these equations by a method of successive approximations, adopting the Rayleigh-Janzen method, i.e. we set

$$\psi = \psi^{(0)} + M^2 \psi^{(1)} + O(M^4), \quad [M = U/c_0] \quad \dots \dots \dots (E)$$

and retain only terms of the order M^2 .

It is well known that the Chaplygin-Kármán-Tsien approximation involves the neglect of terms of the order M^4 ; thus our use of the *CKT* approximation in deriving the equation (D) is consistent with the subsequent procedure of neglecting terms of the order M^4 in the expansion for ψ . Substitution of (E) in (D) yields

$$\frac{\rho_0}{\rho} = 1 + \frac{M^2}{2U^2} \{ \psi_x^{(0)2} + \psi_y^{(0)2} - 2kU\psi^{(0)} - U^2 \} + O(M^4). \quad \dots \dots \dots (F)$$

Inserting (E) and (F) into (C) and comparing coefficients of powers of M^2 on both sides, we get the following equations:

$$\psi_{xx}^{(0)} + \psi_{yy}^{(0)} = kU \quad \dots \dots \dots (G)$$

$$\psi_{xx}^{(1)} + \psi_{yy}^{(1)} = kU + 2k^2\psi^{(0)} - \frac{1}{U^2} \left[\psi_x^{(0)2} \psi_{xx}^{(0)} + \psi_y^{(0)2} \psi_{yy}^{(0)} + 2\psi_x^{(0)} \psi_y^{(0)} \psi_{xy}^{(0)} \right]. \quad \dots \dots \dots (H)$$

The first of these equations corresponds to the solution of the problem for $M = 0$, i.e. the incompressible case treated by Tsien. Taking for $\psi^{(0)}$ the solution given by Tsien for the circular cylinder, we have the equation (H) for the determination of $\psi^{(1)}$. With the determination of $\psi^{(1)}$, the density ρ and hence the pressure are also determined, and the force and the moment are determined by the usual formulae. It is thus found that the effect of compressibility is not only to increase the lift, but also to produce a drag. The lift-and-drag-coefficients are

$$C_L = C_L^{(0)} (1 + \lambda), \quad \lambda = (2.021 + 0.327K^2)M^2, \\ C_D = 2.618K^2M^2$$

where $C_L^{(0)}$ is the lift coefficient for the incompressible case and K is the non-dimensional velocity-gradient in the main stream.

A paper embodying these results has been communicated for publication in the *Quarterly of Applied Mathematics*.

Tsien has also worked out the solution for the flow past a symmetric Joukowski airfoil and by taking this solution for $\psi^{(0)}$ in the above formulae we obtain the compressible shear flow past the airfoil.

Name of Research Fellow . . Mr. S. Vedaraman.

Subject of Research . . Adsorption of gases by industrially important catalysis and kinetics of gas reaction.

(October 1, 1948—September 30, 1949.)

1. Construction of a new Adsorption Unit made of all pyrex glass which can measure adsorption correct to 1/100th of a c.c. Photostatic copy attached.
2. Adsorption isotherms of hydrogen on standard synthetic methanol catalyst $\text{ZnO-Cr}_2\text{O}_3$ (composition ZnO 75% and Cr_2O_3 25%).
3. Adsorption isotherms of carbon monoxide on $\text{ZnO-Cr}_2\text{O}_3$.
4. Adsorption isotherms of hydrogen on a newly developed promoted methanol catalyst (copper 50-15%, zinc 36-0%, TiO_2 12-03%, Th 1-55%, and Ce 0-25%).
5. Adsorption isotherms of carbon monoxide on the promoted methanol catalyst.
6. Adsorption studies of hydrogen on copper and iron phthalocyanines.
7. Adsorption studies of nitrogen on phthalocyanines and their metallic derivatives.
8. Adsorption isotherms of hydrogen on a newly developed Fischer Tropsch catalyst ($\text{Ni-ThO}_2\text{-SiO}_2$ gel).
9. Sorption of hydrogen on poisoned nickel catalyst.
10. Development of a new volumetric static technique for the measurement of adsorption of gases on catalysts of industrial importance at elevated pressures— diagram attached.
11. Adsorption isotherms of hydrogen on $\text{ZnO-Cr}_2\text{O}_3$ at elevated pressures.
12. Velocity of adsorption of H_2 and CO on $\text{ZnO-Cr}_2\text{O}_3$.
13. Energies of activated adsorption have been calculated.
14. Isobars for individual gases have been drawn.
15. Heats of adsorption of the gases on catalysts have been calculated.

(b) FINAL REPORT.

Name of Research Fellow . . Mr. P. A. Ramakrishna Iyer.

Subject of Research . . Studies on reproduction in bats.

1. *Some aspects of reproduction in Rhinolophus rouxi (Temn.).*

Previous work on reproduction in insectivorous bats.

Reproduction of the insectivorous bats of the temperate regions has attracted considerable attention of Continental workers for over a century, and more recently in England and America. The observations generally support the view that autumn constitutes the mating season and that the spermatozoa received from the fall copulations are responsible for the activation of the mature ova which are released during the spring. The spermatozoa of the fall inseminations survive hibernation in a quiescent state either in the uterus in the family Vespertilionidae (Robin, 1881; Grosser, 1903; Courier, 1927; Nakano, 1928); or in a ventral outpocketing of the vagina in the family Rhinolophidae (Fries, 1889; Courier, 1927; Harrison Mathews, 1937). Ovulation takes place and the fertilization occurs in the spring by the stored spermatozoa.

The late winter and spring matings as well as original fall matings are definitely known to occur (Robin, 1881; Duval, 1895; Guthrie, 1933; Caffier and Kalbow, 1934; Wimsatt, 1944). The possibility of winter and early spring copulations are denied by Grosser (1903) and Harrison Mathews (1937), whose observations were based on the presence of a vaginal plug during hibernation. These are cast out in the spring and the ova released are fertilised by one of the stored spermatozoa. This observation found further support from the works of Gates (1936) on *Myotis sodalis* and *Myotis l. lucifugus* and Folk (1940) in *Eptesicus f. fuscus*. Wimsatt (1942 and 1944) provided experimental evidence in *Myotis l. lucifugus* and *Eptesicus f. fuscus*, that the spermatozoa introduced into the uterus of the females at the end of the fall insemination remained functionally alive within the uterus throughout the hibernation period, which lasts for several months, and under normal conditions initiate normal development after fertilisation of the ova released from the ovary in the spring.

The exception to the above is provided by the observations of Hartman and Cuyler (1927) on *Nyctinomus mexicanus* from Texas, which though essentially a temperate species, exhibits a short copulating season in spring resulting in immediate fertilization of the egg and development of the embryo. Storage of sperms is not found in the uterus except at this short copulating season.

Previous work on tropical insectivorous bats.

Little is known on this subject on tropical insectivorous bats. Our knowledge, till recently, was limited to occasional records of pregnancies. One such instance is provided by Yerbury

and Thomas (1895) from Aden, where they noticed pregnancies in three species of insectivorous bats during the months of March and April.

Phillips' studies on Ceylonese microchiroptera convey the general idea that they are monoestrous, with the exception of *Pipistrellus pipistrellus*, which, according to him, 'seem to breed all the year round'.

The first full study of the reproduction of any tropical insectivorous bat is that by Baker and Bird (1936) from New Hebrides. Their study was chiefly centred on *Miniopterus australis* and recorded the presence of a sharply defined breeding season at a time corresponding with the southern spring. Fertilisation and development of the embryo proceeds without delay after copulation, unlike what is seen generally in temperate species, where hibernation occurs. There is no evidence of prolonged storage of spermatozoa in the genital tract of the female though a few are found in the uterine glands during the early pregnancy. Brief reports are also added by them on the reproduction of three other species of insectivorous bats.

The studies of Harrison Mathews (1942) on the reproduction of South African bats adds to our knowledge on this subject. From a similarity of the state of the male and female genital tracts of the species he studied, he concluded that they point towards the occurrence of definite breeding seasons, which correspond roughly with those found in *Miniopterus australis*, studied by Baker and Bird (1936).

With the idea of determining the reproductive behaviour of Indian Chiroptera this study was undertaken.

Observations on reproduction in Rhinolophus rouxi (Temm.).

Material.—An extensive collection of about 650 specimens of this horseshoe bat *Rhinolophus rouxi* was made from an old well about 45 miles from Bangalore, where they are available in large numbers. They were collected by means of nets, as they returned to their haunt, after their usual feed, about midnight. The number collected is large and distributed through the year. The results are based entirely on a study of specimens in a wild state.

Sex-ratio.—A disproportionate ratio of about 62% favouring the females was observed. This percentage of males to females might be taken as correct, since the animals were procured in the wild state and no discrimination was exercised in collecting.

Age and growth.—Kund Anderson (1917), based on a study of teeth of this species of bat, stated, 'Five or six years as the extreme possible age of this bat' and added, 'If one should have hazarded a simple guess at the possible age limit of a bat of this size, it would have been very much the same.' My own studies in this direction confirm the view of Kund Anderson. The age limit of this horseshoe bat appears to be only five years and the sixth year of life is very doubtful. The evidence at hand at present is not in favour of stating that the young-born reach sexual maturity in their first season.

The collection included none which was definitely too small to be adult, taking into consideration their size. Some were sexually immature during the breeding season. The immature males could be detected by the very small size of the testes, absence of lumina in the seminiferous tubules and the absence of spermatozoa in the epididymides; and the females by the immature condition of the ovaries which show only a small degree of growth and activity, and also the almost equal size of the two uterine cornua when compared with the females experiencing their first breeding season.

Males.—The testes in the mature males are in active spermatogenesis and reach their maximum weight during the months of September, October and November. The epididymides are abundant with spermatozoa. The regression of the testes begins in the latter part of December and the sections of the testes show that the involution of the seminiferous tubules is in progress during the months following.

Females.—The mature females during the third week of November did not show any visible signs of pregnancy. Serial sections of the female genitalia did not reveal the presence of spermatozoa in the uterus. The right ovaries of the mature females contained Graafian follicles with much liquor folliculi suggestive of impending early insemination and ovulation. Only one follicle is ruptured each year.

During early December, the mature females fell into two groups: those which had copulated and contained early and late morulae with the zona pellucida in tact and blastocysts which had not yet become implanted; those females which had copulated but had not yet ovulated and lastly, those which were awaiting insemination prior to ovulation.

Period of copulation.—It is suggestive from the foregoing data that insemination and ovulation occurs between the latter part of November and early December, when the days are beginning to get shorter and the temperature is falling. Fertilisation and development of the embryo proceeds without delay after copulation. There is no evidence of storage of spermatozoa in the genital tract of the female.

Parturition.—Young are born in the latter part of April and early May. The period of gestation is about 150 days. The young are born with eyes closed, flesh coloured all over and practically naked.

There is only one young at each pregnancy, which was without exception in the right horn of the uterus. Ovulation from the right ovary appears usual and only one corpus luteum is present in the right ovary of the pregnant females.

The studies point to the conclusion that *Rhinolophus rouxi* is monoestrous exhibiting a limited but distinct breeding season.

2. Reproduction in *Cynopterus sphinx sphinx* (Vahl.).

Previous work on reproduction in fruit bats.—Meagre is our knowledge of the reproduction of fruit bats. Available data on this subject show that they are monoestrous. Three species, viz. *Pteropus giganteus*, *Rousettus aegyptiacus* and *Rousettus leachii*, appear to be polyoestrous at any rate in the zoos, but it does not follow that they are polyoestrous in their native habitat.

It will not be out of place to record here the statement of Marshall (1922) that 'it does not appear to be known whether the polyoestrous condition ever occurs in bats'. Since then a few examples demonstrating this phenomenon in bats have come to light.

Among the Microchiroptera, the Phyllostomid bat *Carollia peripicillata* (Hamlett, 1933) appears to be polyoestrous; similarly among the African species *Chaerophon pulchus* (Braestrup, 1933), *Nycteris luteola* and *N. hispidula* (Mathews, 1942). Mathews (1939) also described the phenomenon of post-partum oestrus in *Nycteris luteola*.

The investigations of Baker and Baker (1936) offered evidence that two species of fruit bats, *Pteropus geddiei* and *P. cotinus*, from New Hebrides were monoestrous, presenting distinct breeding seasons.

Phillips (1936) found in the Ceylonese fruit bat *Cynopterus sphinx sphinx* (Vahl.) females with young during most months of the year and suggested that the breeding was probably intermittent through the year.

Observations on *Cynopterus sphinx sphinx* (Vahl.).

The reproduction in this fruit bat varies from the other examples cited in which information is available. There are two pregnancies in succession in the month of March, suggesting the polyoestrous condition in this species. Further study alone can determine whether the breeding is continuous or is restricted to any definite period of the year.

Bats of this species collected from two localities, in the latter half of the month of March contained females in lactation with the young attached to the nipples. Among them some females had copulated and contained spermatozoa in the uterus, while others were in early pregnancy. The collection included also males in full functional activity. This phenomenon of post-partum oestrus in a fruit bat in its native habitat is recorded.

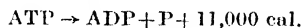
The pregnancy alternates between the two horns of the uterus and the ovaries ovulate alternately. One corpus luteum was present in the ovary of the same side of the pregnancy, which persisted till parturition. Only one young is produced at each birth.

Name of Research Fellow . . . Dr. N. K. Sarkar.

Subject of Research . . . Studies in certain aspects of the chemistry and physiology of snake-bite.

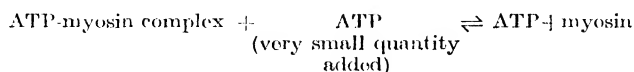
(October 10, 1947—October 9, 1948.)

From the behaviours of nerve and muscle in cardiotoxin solution, it has been inferred that the cardiotoxin acts directly on the muscle, leaving aside the nerve and neuro-muscular junction intact. The cobra venom, however, on the other hand, acts both on the muscle and the neuro-muscular junction. The present work has been undertaken with a view to elucidating the mechanism of irreversible contraction of muscle brought about by venoms, digitalis and other allied drugs. The vast amount of literature that has accumulated on the subject of muscular contraction indicates that the energy required for the contraction of muscle is obtained from the breakdown of adenosine triphosphate (ATP) into adenosine diphosphate and phosphoric acid, in presence of myosin which acts as an enzyme.



Assuming this to be true, in every case, a large number of experiments have been done to study the effects of venoms and other drugs *in vitro* on the breakdown of ATP. Out of all these substances only cobra venom can bring about the breakdown of ATP, even without the presence of myosin. So far so, the action of cobra venom on the contraction of muscle can be understood, but the cause of contraction, brought about by cardiotoxin and other drugs, could not be explained on the basis of this explanation; because of the fact that none of them has got any phosphatase activity and could not bring about the breakdown of ATP. Experiments with cardiotoxin,

digitalis, etc. have also been done with extracts of diaphragm muscle of pigeons, and the results are found to be the same. Cobra venom heated at 55°C. for $\frac{1}{2}$ hour loses its phosphatase activity, but even then this heated venom solution can bring about the stoppage of the movements of an isolated heart and can produce contraction of gastrocnemius muscle. All these results therefore indicate that the breakdown of adenosine triphosphate is not the primary cause of contraction. The more recent work of Szent-Gyorgyi and his colleagues has led them to the conclusion that the release of ATP from ATP-myosin complex is the primary cause of contraction rather than the breakdown of ATP into ADP, and P. Buchthal, Deutsch and Knappes (1944) discovered that ATP, applied to an isolated muscle fibre, produces twitches or a tetanus-like contraction which in many ways resemble normal contraction, and they arrived at the conclusion that ATP is involved in the process of excitation and that ATP present in the muscle is in the inactive condition. Rozsa used freshly isolated muscle fibres and found that 0.5% of ATP per ml. suffices to cause contraction. The amount of ATP present in the muscle is roughly 500 times greater than the amount required to elicit contraction. He suggests that these small concentrations of ATP added did not elicit contraction directly but activated the relatively large quantity of ATP present in muscle in an inactive condition; so that the ATP present in the fibre now behaved as free ATP. Knowing that the ATP present in the muscle is adsorbed to myosin, it is difficult to believe how ATP, added from outside, can help the release of ATP from ATP-myosin complex, if we consider the following equilibrium existing in the muscle system. According to the law of mass action, the addition of ATP from outside should actually prevent rather than facilitate the release of ATP.



Therefore, some other mechanism is involved in the mechanism of contraction of muscle, which we are unable at present to say what it is exactly.

That the mechanism of contraction in the case of cobra venom digitalis and other allied drugs is different from the one already stated, is further strengthened from the results obtained with inexcitable muscles. Small amounts of ATP (0.5%), added from outside, could not elicit contraction of an inexcitable muscle while cobra venom, digitalis and even Ca can produce contraction of such an inexcitable muscle. The term irritability, according to modern usage, means that a tissue can be made to exhibit its peculiar form of functional activity when stimulated, e.g. a muscle cell will contract, a gland will secrete. Muscle loses its irritability when treated with an isotonic solution of arabinose, glucose, fructose, saccharose, and other saccharides or 0.25M KCl.

The loss of excitability of a muscle has been observed in solutions of all of these substances having a very wide range of concentration. Only the time required for the loss of irritability increases with dilution. Cobra venom, digitalis, and mono- and di-valent inorganic ions like Li, Na, K, Rb, Cs, Ca, Ba, Sr, Mg are very similar in their behaviour in producing inexcitability. The most interesting point, of all the observations, is that muscle dipped into a solution of cobra venom, digitalis or Ca not only becomes inexcitable, but also shows contraction. In the case of cobra venom, when the muscle has attained its maximum height of contraction, depending upon the concentration of the venom solution, even then the muscle has been found to exhibit excitability; of course more powerful stimulus is required to excite the muscle. Just the opposite is the case with Ca solution. In this case the muscle loses its irritability completely before it has attained the maximum contraction. Furthermore, it has been observed that cobra venom, digitalis and divalent inorganic ions can produce contraction of an inexcitable muscle. To sum up, therefore, all these evidences go to show that the cause of excitability and contractility is different from each other.

Fenn has pointed out that the cause of inexcitability of a muscle is due to a loss of K from it, and he has been able to show that the muscle remains all the while excitable when a critical concentration of KCl solution is used as a medium. In our series of experiments, we observed that of all the monovalent ions, K is most effective in reducing the excitability of a muscle when used over a wide range of concentration. Practically speaking, even the using of a solution, having a concentration greater than 0.1M (isotonic with respect to frog's muscle), could not prevent the loss of irritability. Certain non-electrolytes like arabinose, glucose, fructose, saccharose, etc. are also quite effective in reducing the excitability and quantitative estimations of K and Na in muscle, as carried out by Fenn and others, showed that the loss of K in non-electrolyte solutions is very small when compared with the loss of Na and chloride ions. This also proves conclusively that the loss of K from the muscle is not the cause. All other mono- and di-valent ions also behave in a similar way to that of K; except that almost all the divalent ions over and above this can elicit contraction of an inexcitable muscle. Another interesting point is that 0.45M KCl not only reduces the excitability to zero, but also produces contraction of the muscle at a later phase of its action. The cause of inexcitability as observed with 0.25M KCl is, according to Szent-Gyorgyi, due to prevention of the release of ATP by making its adsorption too strong with myosin. But this explanation also fails when we consider the inexcitability of a muscle caused by non-electrolytes.

We are thus far off from any theory or theories which will explain the behaviour of a muscle with respect to excitability and contractility in ionic and non-ionic solutions. We are therefore continuing the work on the nature of actions of ionic and non-electrolytic solutions on muscle.

We have already studied the effects of different cations on excitability of isolated gastrocnemius muscle of a frog, and from the results obtained, we were unable to explain the respective behaviours of different ions simply on the basis of hydration values of ions. Assuming the muscle membrane to be a sieve-like collodion membrane, the permeability of ions then mainly depends upon the size of the ion; the greater the hydration value (i.e. the number of water molecules attached) the greater will be the size of the hydrated ion and consequently the lesser will be the chance of permeability. Knowing the hydration values of Li, Na, K, Rb, Cs, Ca, etc., and assuming the said hypothesis to be correct, then the corresponding times as calculated and as obtained experimentally should have been of the same order; though this has not been found to be the case. If we consider the adsorption affinity of the colloids toward the ions, which differs from ion to ion and which also increases with decreasing hydration (together with the hydration values of ions), the results obtained with cations could be correlated to a greater extent, though we cannot say exactly how far we shall be able to explain these observations. If we consider another factor which is the competition for water between the colloid and the outside ions, over and above the assumptions made, then possibly we shall be able to explain these facts. As we do not know, so far, the comparative values of the affinity for water, we are not in a position to say anything definitely.

The behaviour of divalent inorganic ions is very interesting. Following the addition of Ca-salt, muscle not only loses its excitability but at the same time shows contraction. The time required for the loss of excitability and the height of contraction has, however, been observed to depend on the concentration of the salt solution used. This peculiar behaviour of muscle has also been observed with Ba, though to a lesser degree. Mg, however, except at high concentration, could not produce any contraction of the muscle. Though the permeability of Ca through the muscle membrane has been denied by most of the workers, the peculiar behaviour of Ca can only be explained if we imagine that some insoluble Ca-protein salt is formed at the time of its entrance through the membrane, increasing thereby the size of the pores, through which ions are supposed to pass through. Over and above this, the affinity of Ca for water is very great. Following the addition of CaCl_2 to a gel or hydrophilic colloid dehydration, in other words, shrinking or stiffening occurs indicating the competition for water by the highly hydrated Ca. Thus the physiological effects parallel the physicochemical reactions.

The effects of anions on the excitability of muscle has also been studied. Here again the question of permeability of anions through muscle is important. There is a great controversy over the question of permeability of anions through the muscle membrane. To give an explanation of the experimental results, we shall have to assume the permeability of anions too, as by using isotonic solutions of different K-salts, the time required for the complete loss of excitability has been found to differ from one another. In such cases also, mere 'hydration' is not enough to explain their actions; and the anions are arranged according to their capacities in lowering the excitability of muscle as SCN , I , Br , NO_3 , Cl , SO_4 . Even over a wide range of concentration as used in our experiments the order of anions has been found not to be altered, though such a reversal of the order has been mentioned in the literature.

The work on excitability indicates that any one of the alkali or alkaline earth ions cannot maintain the excitability of the muscle for a long time, even the addition of another ion like K or any other ion, i.e. the combination of two different ions, is also not sufficient for the purpose. But of all these ions Na, K and Ca, when present in a certain definite composition, can maintain the excitability for a long time and this solution is known as Ringer. Except the combination of Na, K and Ca, combination of any other three ions could not produce the same result and possibly this is due to the presence of these three metals (Na, K, Ca) in the muscle. These points are still to be confirmed.

Name of Research Fellow . . . Dr. P. C. Mukharji.

Subject of Research . . . Synthesis of steroid sex-hormones and hormones of Adrenal Cortex.

(August 23, 1948—August 22, 1949.)

Two different methods for the synthesis of steroid compounds have been successfully explored a few years ago (Mukharji, *J. Ind. Chem. Soc.*, **24**, 91, 1947 **25**, 365, 373, 1948). The extension of these methods for the synthesis of the natural steroid hormones, and their related analogues, forms the subject-matter of the present study. During the period under review the application of these two methods for the synthesis of the female sex hormone Oestrone has been undertaken and the study is still being continued.

The basic organic chemicals required for this investigation, e.g. meta-hydroxy-benzaldehyde, meta-bromo-phenol, β -chloro-propionic acid, could not be procured from the local market and

considerable quantities of each of these compounds had to be prepared in the laboratory for the proposed work.

For the first method, a fairly large quantity of 6-methoxy-3:4-dihydro-1-naphthoic acid being necessary, the compound has been prepared from meta-hydroxy-benzaldehyde following the method of Birch and Robinson (*J. Chem. Soc.*, 1944, 503). Useful modifications at some of the intermediate steps have been introduced with advantage and the above acid has been obtained in ca. 20% overall yield from the hydroxy benzaldehyde. Experiments for the conversion of this acid to the corresponding methyl ketone with cadmium dimethyl proved to be entirely unsatisfactory both with regard to yield and purity of the reaction product, and a number of other methods are being investigated now to find out the optimum conditions for this conversion.

Following the second method, the synthesis of the valuable intermediate compound, ethyl-(2-methyl-2- β -carbethoxyethyl-cyclopentyl)-(β -meta-methoxy-phenyl ethyl)-acetate has been completed. From this compound the tetracyclic ring system characteristic of Oestrone can be built up in four steps and work in this direction is being continued.

C. IMPERIAL CHEMICAL INDUSTRIES (INDIA) RESEARCH FELLOWSHIP.

(a) FIRST ANNUAL REPORT.

Name of Research Fellow .. Mr. H. N. Bose.

Subject of Research .. Luminescence spectra of different types of phosphors under X-rays and cathode rays, specially at low temperatures.

(November 15, 1947—November 14, 1948.)

A systematic investigation of the luminescence of solids under X-ray and cathode ray excitation has been undertaken; the solids chosen are the alkali halides, some of the structurally simplest of inorganic compounds, which have attracted the largest amount of attention from the theoretical workers of solid physics. A few simple organic compounds, viz. Naphthalene, Anthracene, etc., have also been studied. The ultraviolet luminescence spectra have also been taken, wherever possible, for the sake of comparison.

Special apparatus for studying the luminescence spectra under cathode rays at ordinary temperature as well as at liquid oxygen temperature has been constructed and set up. The luminescence spectra of NaCl, KCl, KBr, KI, KBr-Tl, KI-Tl, KI-Ag, KI-Pb, KI-Cu and KI-Mn have been obtained at room temperature and most of them at low temperature. In order to study the visible part of the luminescence spectra these measurements have been carried out with a glass spectrograph.

X-ray irradiation of these crystals are known to create a number of centres, viz. F , R_1 , R_2 , etc. which are obtained only in absorption. The results obtained in the present investigation seem to indicate the presence of these centres in emission as well.

Impurities included in the alkali halides have no marked influence on the luminescence spectra of the parent lattice, the characteristic impurity band appearing along with those of the parent matrix. Thus in the case KI-Tl, NaCl-Tl pure spectrum is not much affected by the presence of the characteristic Tl band in the ultraviolet region. Further, the results indicate that some of the emission peaks, as obtained by previous authors and supposed to be due to Tl impurity, are most likely due to the parent lattice and not connected with Thallium. The emission of the pure alkali-halides consists, in general, of a number of extended bands which gradually increase in width with frequency. The emission is further characterised by a long wavelength band rather sharp and fairly strong, which has almost the same position in all the alkali-halides. It is further interesting to note that this band is absent in phosphorescence.

The work is being continued at low temperature.

SECOND ANNUAL REPORT.

(November 15, 1948—November 14, 1949.)

The luminescence spectra of some of the alkali-halides, pure and impurity activated, under cathode ray excitation have been investigated at ordinary and low temperature with the help

of a cathode ray tube specially designed for the purpose. It has been found that pure specimens, which are non-luminescent under ultraviolet excitation, emit a spectra composed of a number of diffuse bands. The effect of different impurities, when added to the melt or as mechanical mixtures, has been investigated; the effect of concentration on the luminescence spectra has been studied for the system KI+Tl. Comparing the measurements with the ultraviolet luminescence spectra of impurity activated alkali-halides, it is observed that part of the emission by ultraviolet excitation can be explained as that of the pure matrix emission which is obtained under X-rays or cathode rays. The existence of emission, similar to that of TlCl, in the luminescence spectra of alkali-halides with high thallium content, indicates an identical environment for the thallium ions in these phosphors and thallous chloride. Easy transfer of excitation energy between the centres, induced by cathode rays or X-rays, and those due to activators, occurs very frequently; it is further suspected that activation of alkali-halides by thallium is a case of indirect activation for that part of the spectra which is common in the activated and pure alkali-halides under ultraviolet and X-ray or cathode rays respectively.

Although the exact nature of the emitting centres in alkali-halides is still obscure, some general ideas can be obtained from the present investigation. Absence of luminescence by ultraviolet excitation indicates that the emitting centres are not present in pure crystals and they are created by X-ray or cathode ray irradiation. In view of the fact that inclusion of foreign impurities induces an emission of X-ray or cathode ray luminescence spectrum of pure alkali-halides, even under ultraviolet excitation, it is natural to suppose that the emitting centres are sometimes created by the impurities also. Besides, transfer of energy takes place between two types of centres in all cases; since the samples are known to be non-conducting under these conditions, energy transfer occurs either by quantum-mechanical resonance process or by self-absorption, but as the same emitting centres are created by X-rays or cathode rays and impurities, the parent matrix emission is probably due to the energy states of the ions perturbed by the presence of the impurities or similar lattice defects. Further, the luminescence spectrum under X-rays or cathode rays being mostly due to the recombination of free electrons from the conduction band with the emission centres, only those centres which have excited states near to the conduction band will be naturally more effective than those having excited states far below. This may be the explanation why the impurities, which are effective activators in ultraviolet excitation, do not sometimes play as important a rôle in the case of X-ray or cathode ray excitation.

In order to study the long period decay curves of these phosphors under the present method of excitation, a photo-multiplier (931A) with necessary circuits has been set up; the output current is proportional to the intensity of light and could be measured directly with a microammeter without amplification. The dark current could be maintained at 1.5 micro-amps. and the voltage per dynode varied between 50 to 70 volts. The decay of intensity of luminescence under cathode rays has been studied for a number of alkali-halides at different temperatures with different intensities of excitation. The bi-molecular law is not capable of explaining the curves; they can, however, be explained by assuming the presence of one or more trapping mechanisms inside the crystal, and that phosphorescence is due to the time taken by the electrons to be released from these traps. There is further evidence that the trapping centres are different from the emitting centres.

A D.C. amplifier has been set up; this is being used along with a cathode ray oscillograph to investigate the type of decay just at the beginning. A method of determining accurately the trap depths from thermo-luminescence data has been developed and the necessary apparatus for the purpose designed.

The luminescence spectra of some organic compounds have been studied under cathode rays and X-ray excitation. Interesting variations from U.V. luminescence have been observed; with naphthalene, in addition to the vibration bands in the ultraviolet region (obtained in U.V. excitation), a number of visible bands are obtained under X-rays, while by cathode rays only visible bands appear, the vibration bands being entirely absent. Under cathode rays some of the organic compounds have remarkable afterglows with prominent maxima in the glow curve.

ANNUAL REPORT.

Name of Research Fellow . . Mr. S. P. Basu.

Subject of Research . . Ecology of sewage-irrigated fisheries in the Bidyadhari spill area, with particular reference to the bionomics of carps cultured therein.

(July 16, 1947—July 15, 1948.)

The scheme commenced on the 16th July, 1947. Observations were made on the working of the two fisheries, namely, Hanakhali (600 acres) and Charcharia (250 acres), both being favourably situated for fish-farming in the defunct Bidyadhari spill area and are irrigated by Calcutta sewage. All the fisheries in this area are shallow, ranging in depth from 2 to 4 feet. The local practices

of fish-farming and sewage irrigation were studied in detail and an attempt was made to correlate them with the physical, chemical and biological factors of the fishery waters.

The Salt Lakes cover an area of about 75 square miles, of which 50 square miles are marshy and unsuitable for agriculture. Out of these 50 square miles, 27 have been converted into fisheries yielding 120,000 mds. (4,445 tons) of fish annually. The remaining portion can be profitably converted into fisheries and the production will then increase to 3 lakh mds. (11,100 tons). Standardisation of sewage feeding is, therefore, a problem of great economic importance and hence this research was undertaken.

Sewage is fed once a month during the summer and winter months, while during the monsoon months, the fisheries are drained off to check overflowing. Sewage is allowed to enter against the direction of wind and 30 to 40 million gallons of sewage is mixed with 100 to 120 million gallons of fishery water slowly in course of 5 to 10 days, thereby reducing the chance of sudden pollution and fish mortality during sewage feeding. Fisheries are dried up for one or two months for periodic cleaning of vegetation and drying the bottom. Sometimes paddy is cultivated as an alternating crop to prevent the soil getting sewage-sick.

Typha sp., *Eichloronia crassipes* Solms, *Pistia stratiotes* Linn., *Lemna* sp., *Ceratophyllum demersum* Linn., *Tribonema bombycinum* (Ag.) Derbis and Sol., *Vallisneria spiralis* Linn., different species of *Cyperus*, *Nitella*, *Chara*, *Oedogonium*, etc. form the natural aquatic vegetation, while *Panicum* sp., *Suaeda maritima* Dumort, *Alternanthera sessilis* Br., etc. constitute the terrestrial vegetation. Marginal vegetation of 50' is kept to check the erosion of embankment. Seasonal variation in the above vegetation was also observed. Growth of *Pistia stratiotes* Linn., *Lemna* sp., *Azolla pinnata* R.Br., *Ceratophyllum demersum* Linn. is vigorous in summer, while *Vallisneria spiralis* Linn., *Oedogonium* sp. and *Tribonema bombycinum* (Ag.) Derbis and Sol. were prominent during winter.

Growth of Cladocera and phytoplankton is prominent in summer, while that of Copepoda, Rotifers and Protozoa is moderate. In monsoon months, Cladocera, Copepoda and phytoplankton grow in moderation, while Rotifers and Protozoa are prominent. Plankton content is negligible in winter.

Ophicephalids, Siluroids, Anabantidae and Minnows form a natural by-product in these fisheries in addition to the carps (*Catla catla*, *Labeo rohita*, *Cirrhina mrigala*, *Labeo calbasu*, *Labeo bata*) cultured therein.

Surface temperature of water varies in summer from 89°F. to 93°F., in monsoon 84°F. to 91°F., and in winter 60°F. to 80°F.

Dissolved oxygen varies in summer from 7.6 to 8.6 p.p.m., in monsoon 6.6-7.6 p.p.m., and in winter 8.2-9.8 p.p.m.

Carbon dioxide remains in traces, except during sewage feeding when it varies from 22 to 20 p.p.m. in the zone of pollution.

pH varies in summer from 8.3 to 8.5, in monsoon 8.2-8.4, and in winter 8-8.4.

Chloride varies in summer from 340 to 500 p.p.m., in monsoon 104-360 p.p.m., and in winter 112-296 p.p.m.

A marked diurnal variation in the dissolved oxygen and pH was noticed. In the morning D.O. was 6 p.p.m. and in the evening 14.6 p.p.m., while pH was 8 and 9.8 respectively.

D.O. becomes nil and CO₂ increases in the zone of pollution after sewage feeding. Sewage fed to the fisheries has 100-115 p.p. B.O.D. Nitrates and phosphates do increase. B.O.D. increases to 70-92.5 in the zone of pollution and comes to normal in 10-12 days in summer while it takes 15 to 20 days in winter.

Bacteria increase after sewage feeding on the 1st day, while Protozoa, Rotifers and Crustacea increase on the 2nd, 3rd and 4th day successively. Phytoplankton increases on the 3rd day. Decrease in phytoplankton is followed by decrease in zooplankton.

In course of a year from 1 cm. fry, *Catla catla*, *Labeo rohita*, *Cirrhina mrigala* attain a length of 40 cm., 30 cm., 25 cm. and weigh 1½ lb., 1¼ lb. and 1 lb. respectively.

70% *Labeo rohita* and 30% *Cirrhina mrigala* are infected with myxosporidian parasites during summer, *Catla catla* being free from infection. 80% *Catla catla* and 20% *Cirrhina mrigala* were infected in winter, *Labeo rohita* being free from infection. In monsoon months there was no infection.

These preliminary observations were recorded and experimental ponds were excavated to get scientific data under controlled conditions, but due to local agitation against the feeding of fisheries with sewage, the work had to be abandoned and a new problem on 'The effect of some physico-chemical factors on Indian food fishes' taken up in October 1948, with the approval of the Council.

Name of Research Fellow . . Mr. T. V. Desikachary.

Subject of Research . . Morphology and Taxonomy of some South Indian Algae.

(September 11, 1948—September 10, 1949.)

The Algal Flora of some South Indian Mountain Streams.

Very little is known of the algal flora, especially the encrusting algae, of our hill streams and their hydrobiology. In England and other countries some work has been done on this aspect of stream algae by Fritsch, Butcher, Geitler and Ruttner. An attempt is made now to study this aspect with special reference to periodicity and seasonal succession and hydrology. Two mountain streams near Tirupati (a place 90 miles from Madras), viz. Akasaganga and Papanasam, have been selected for a study of their algal flora and the physical and chemical features of their waters, and in this scheme of work the periodicity and seasonal succession of some of the chief forms have also been studied. For this purpose fortnightly visits were made to these streams throughout the year. These visits will be continued till the end of November 1949 to complete a 12-month observation of the streams. Meteorological data have also been recorded throughout the period of these visits.

For purposes of comparison a relatively polluted mountain stream in the same locality has also been studied for a short period for its hydrology, algal flora and their ecological distribution.

A general study of the algal flora of another hill stream at Kambakkam near Madras is also under progress.

Preliminary work on an illustrated, descriptive and systematic account of some South Indian Marine Phaeophyceae in Professor M. O. P. Jyengar's collection has been completed and detailed study of each species is under progress.

Name of Research Fellow . . Mr. Jyotirmay Mitra.

Subject of Research . . Artificial culture of embryo and study of factors influencing the successful growth of embryo in synthetic media under tropical conditions.

(October 1, 1948—September 30, 1949.)

The present investigation deals with the problem of the culture of excised embryos in synthetic media under tropical conditions. This type of work has already been carried out in temperate countries, particularly in America, with success. Thus, with a view to obtaining similar results in tropical countries this work has been undertaken.

In the present investigation, experiments are being conducted mainly with jute embryos under different conditions. Later on, other plants of economic importance will be taken up.

The seeds of the field-grown plants were properly disinfected and the excised embryos were cultured in agar media containing nutrient salts and sugar according to Tukey's formula.

Two series of trials were given in the present experiment, viz., I. *Experiments done at the room temperature* and II. *Experiments done at lower temperature in the cool-incubator*. In the former category, experiments were conducted exclusively under room conditions. In the second series of experiments, however, dissection and transfer of embryos were made in a thoroughly disinfected culture room and the cultures were kept in a cool-incubator at $23^{\circ}\text{C} \pm 1^{\circ}\text{C}$.

I. *Experiments done at the room temperature*.—The period of this experiment extended from January 1949 to June 1949. For the first three months (January, February and March) the range of minimum and maximum temperature was 22°C . and 29°C . respectively and it was 29°C . and 32°C . for the next period, i.e. April, May and June.

In the first part of the experiments 150 cultures were made both from *Corchorus olitorius* and *C. capsularis* embryos. Growth in the majority of the tubes were extremely slow and microbial contamination in the culture tubes was high. Contamination-free cultures, however, survived only up to seven days. In the second part of the experimental trial 200 cultures were made with increased rate of contamination and having 2% survivors.

II. *Experiments done at lower temperature in the cool-incubator*.—In the second series of experiments embryos of *Corchorus olitorius*, *Musa Agharkarii* and a hybrid between *M. Agharkarii* and *M. superba* were selected. Here all the operations were done in a disinfected culture room and incubated at $23^{\circ}\text{C} \pm 1^{\circ}\text{C}$. Here 92% of the cultures from jute embryos showed healthy growth up to 10 days of incubation period without being contaminated, and a short course of light treatment was given afterwards to the developing embryos soon after the appearance of cotyledons. They were then transferred to soil. 75% of these seedlings ceased to grow after the transference and the remaining continued to grow for another seven days at a slow rate. The first sign of death was drying up and that was located in the cotyledons.

There was no sign of growth in any of the cultures of the banana embryos though they were entirely free from contamination.

Here again, in the second series of experiments controls were set up with equal number of cultures (jute embryos only) which were incubated at the room temperature (29°C .– 30°C .) inside a dark cupboard. The growth was retarded in 88% of the control cultures where the embryos began to shrivel on the 6th day of incubation and they all died by the 8th day. In a few cultures there were signs of contamination on the 4th day of incubation.

It is evident from the above experiments that besides maintenance of aseptic condition during transfer, the influence of incubation temperature might also play an important rôle in affecting the growth of young embryos in synthetic culture media.

Name of Research Fellow . . Dr. C. V. Subramanian.

Subject of Research . . Studies in *Fusaria* from Indian soils, with special reference to physiological races.

(September 10, 1948—September 9, 1949.)

The present investigation was undertaken mainly to elucidate the question of specific identity and occurrence of *Fusarium* species in South Indian cultivated soils. That *Fusarium* species are important pathogens of crop plants in this country is evident from the various reports of provincial mycologists in India. Nevertheless, emphasis on crop culture has been in the past mainly in the direction of breeding new varieties of crop plants resistant to specific soil-borne diseases but not an understanding of the microbial complexes that normally constitute an agronomical problem of great immensity. The author has brought to light in the past the necessity of including in such a breeding programme a detailed study on the status of *Fusaria* in soils—occurrence, saprophytic activity and survival, and pathogenicity—prior to bringing under control through soil management wilt diseases of plants. It may be mentioned that no attempt had been made in this country to study the genus *Fusarium* in detail, as, for instance, has been done for Central American and Philippine soils by Wollenweber, Reinking and Manns. It is therefore obvious that a similar undertaking in this country would result in evaluating the micro-ecological status of soil-borne plant pathogens, particularly the *Fusaria*.

During the year under report the study was mainly devoted to the isolation of the various *Fusaria* that occur as inhabitants of wilt-sick soils and as pathogens of crop plants in South India. The investigation is directed to determine the different species of *Fusaria* that occur in South India and mainly followed the technique of some of the classical investigations by Wollenweber, Reinking and others on the *Fusarium* flora of Central American and Philippine soils. As many as one hundred and fifty isolates have been obtained and these are being studied individually for purposes of identification. So far, the author has recorded the following species:—

1. *Fusarium avenaceum* (Fr.) Sacc.
2. *F. equiseti* (Cda.) Sacc.
3. *F. scirpi* Lamb. et Fautr.
4. *F. scirpi* Lamb. et Fautr. v. *longipes* (Wr. et Rg.) Wr.
5. *F. solani* (Mart.) App. et Wr.
6. *F. solani* (Mart.) App. et Wr. var. *Martii* Wr.
7. *F. solani* (Mart.) App. et Wr. var. *minus* Wr.
8. *F. solani* (Mart.) App. et Wr. var. *striatum* (Sherb.) Wr.
9. *F. udum* Butl.
10. *F. vasinfectum* Atk.

Of these, *F. avenaceum* (Fr.) Sacc., *F. scirpi* Lamb. et Fautr., *F. scirpi* Lamb. et Fautr. v. *longipes* (Wr. et Rg.) Wr., *F. solani* (Mart.) App. et Wr. var. *minus* Wr., and *F. solani* (Mart.) App. et Wr. var. *striatum* (Sherb.) Wr. are new records for India.

A study of the variation exhibited by the various isolates in different culture media (e.g. potato dextrose agar, lupin stems, steamed rice, etc.) is being conducted with reference to the following aspects: (a) colour production; (b) occurrence of sporodochia, pinnules, etc.; (c) shape, size and septation of micro- and macro-conidia; (d) presence of chlamydospores, etc. Trials are also under way for a study of the pathogenicity of the various *Fusarium* species and strains isolated.

(b) FINAL REPORT.

Name of Research Fellow . . Dr. P. C. Bhattacharya.

Subject of Research . . Study of mesotron and the allied problems.

It is known that cosmic radiation consists of two components: soft and hard. The soft component which consists of electrons, positrons, and photons is absorbable in 4–10 cm. of lead and produces cascades in traversing dense material like lead. The behaviour of the soft component is accurately described by the quantum theory and, in particular, by the cascade theory. The hard component consists mainly of mesotrons—particles of mass about 200 times that of an

ordinary electron and the charge is electronic but of either signs. The mesotrons are not stable like electrons or protons but they are found to disintegrate into electrons and neutrinos. The disintegration probability increases as the energy of the mesotron decreases.

The behaviour of the hard component (i.e. of the mesotrons) is not fully understood and, in fact, the energy spectrum, scattering and energy loss of low energy mesotrons are not yet known precisely. Now the only source of mesotrons is in cosmic radiation, but here it is found to be mixed up with the soft components, i.e. electrons (β^+ , β^-) and photons. In order to separate the mesotrons from the electrons the usual method is to put some filter, such as 10 cm. of lead, between the Geiger-Müller counters so as to absorb the soft components. But the serious defect of this method is that the filter absorbs also all the low energy mesotrons of range up to 10 cm. of lead, i.e. of energy up to 2.4×10^8 ev. The number of these low energy mesotrons increases with altitude. Experiments of Malcolm Corroll (1947) suggest that mesotrons of energy between 8×10^7 ev. and 2×10^8 ev. at 11,500 ft. above sea-level are produced by a neutral radiation, although the more energetic ones are believed to be produced by the protons. Similarly, the other characteristics of slow mesons are likely to be quite interesting. But most of these low energy mesotrons are lost in the thick absorber in the process of separation.

Bhabha (1944) suggested a method for the removal of electrons by making the most effective use of the cascade process. In this method a block of lead, 1.25 cm. thick, was used to produce showers. It was placed just below the topmost counter of the telescope and over a counter tray containing two sets of counters attached to an anticoincidence circuit, such that any shower produced in the lead piece were suppressed by the anti-counters. A second piece of lead, 4 cm. thick, was placed below the anti-counters but above the lowest counter of the telescope. The function of the lead piece was to absorb any low energy electron which escaped the system without producing a shower in the upper lead block.

This suggested method of separation of mesotrons from electron was experimentally tested by Dr. P. C. Bhattacharya with a Wilson chamber. For this purpose the four-centimeter lead block of Bhabha was further divided into two pieces of 2 cm. each and one of them was placed across the middle of the Wilson chamber while the other one was placed just above the lowest counter. The lead piece across the chamber served to distinguish between electrons and mesotrons. An electron has a large probability of producing secondaries in traversing the lead block while a mesotron will come out as a single particle.

Dr. Bhattacharya found that the above method of separation of mesotrons from the electrons was quite efficient in sorting out the mesotrons. With this arrangement one can study mesotrons of energy as low as 1.6×10^8 ev., i.e. of range 5.25 cm. of lead. This arrangement can be used for measuring the mesotron intensity at high altitude.

Now the question arises as to whether the additional block of lead of 4 cm. thickness is absolutely necessary or whether it can be reduced or totally dispensed with in case we want to study mesotrons of range lower than 5 cm. of lead. Dr. Bhattacharya has shown that this lead block can be reduced to 2 cm. at sea-level without affecting the efficiency of the process of separation of mesotrons.

In regard to the thickness of the upper lead block an experiment with counters was carried out to ascertain the exact thickness of lead corresponding to the shower maximum of more than one particle and more than two particles initiated by electrons in lead. The experimental results on the separation of mesotrons from electrons were published in *Physical Review*, Vol. 74, pp. 38-43, 1948—a reprint of which is attached herewith.

Calculations of the probabilities of showers of more than one particle and more than two particles were also carried out. These calculations were made on the assumption that fluctuations obey Poisson distribution and that the energy spectrum of the electrons incident on the top lead block is of the form $J(K/E^\alpha)$, where J and K are suitable constants and $\alpha = 2.9$ at sea-level. Another paper consisting of these theoretical considerations is in course of publication.

An article 'On the production of mesons in the laboratory' was published in *Science and Culture*, 13, 477, 1948.

Name of Research Fellow . . . Dr. P. C. Datta.

Subjects of Research . . . 1. Synthesis of the alicyclic systems related to the steroids.
2. Synthesis of sesquiterpenes and the acids isolated from degeneration of these bodies.

Synthetical Experiments in the Alicyclic Systems, Part II.

In part I of this series, an attempt was made to find out a general method for the synthesis of 12-keto-steroids. In the following lines are described, in short, three different methods which have been successfully developed for the synthesis of the tricyclic systems comprising B, C and D rings and the C_{13} -methyl group and the 12-keto group. These methods are capable of extension in order to realise the final objective, i.e. the characteristic tetracyclic system with the iso-octyl group and the two angular methyl groups.

The first method starts from ethyl cyclohexan-1-acetate-2-cyanacetate which condenses with γ -iodobutyric ester to give the cyano-ester (205–210°/2 mm.). This on hydrolysis and esterification gives the desired tricarboxylic ester (195–200°/4 mm.). This is again prepared from the condensation product (176°/3 mm.) of ethyl 2-bromo-cyclohexylidene acetate with ethyl cyclopentanone carboxylate which on reduction and fission with sodium ethoxide gives the same tricarboxylic ester. This on Dieckmann's condensation and subsequent hydrolysis and esterification gives the keto-ester (I, 145–150°/2 mm. semi-carbazone, m.p. 149–50°). This on successive treatment with methyl magnesium iodide, dehydration and hydrolysis gives the desired unsaturated acid (165°/2 mm.). The hydroxy-ester on distillation passes into a neutral substance, the properties of which closely resemble those of a lactone. The acid-chloride of the above undergoes ring closure in presence of stannic chloride and the chloroketone on heating with dimethylaniline gives the unsaturated tricyclic ketone (128–30°/3 mm.) in a poor yield. In presence of potassium, the iso-octyl side chain can be introduced at the methylene group α - to the keto-group of the above keto ester (I).

Ethyl 2-bromocyclohexylidene acetate reacts with ethyl 2-methyl-cyclopentanone-2-carboxylate in presence of magnesium to give the hydroxy ester (165°/2 mm.) which on catalytic reduction is treated with thionyl chloride and pyridine and hydrolysed with alkali. On esterification, the desired dimethyl ester (148°/3 mm.) is obtained, along with a considerable low boiling neutral portions separable into two fractions (95–98°/2 mm. and 125–30°/3 mm.). The dimethyl ester after catalytic reduction undergoes Dieckmann's condensation and on hydrolysis the tricyclic ketone is obtained (135°/3 mm.).

The third method consists of the following steps. Ethyl 2-methylcyclopentanone-2-carboxylate on bromination and on heating with quinoline gives the unsaturated keto-ester. Reduction with aluminium isopropoxide of the above gives the unsaturated alcohol (122°/9 mm.) which gives the bromo-unsaturated ester on treatment with phosphorus tribromide. This condenses with cyclohexanone to give ethyl 2-(2'-ketocyclohexan)- Δ^3 -cyclopentan-1-methyl-1-carboxylate (130–35°/2 mm.). This on reduction and hydrolysis gives the expected keto-acid. This keto-acid has again been prepared by condensing δ -bromo-valeric ester with ethyl 1-methyl-cyclopentan-1-carboxylate-2-cyanacetate. The condensation product (212°/5 mm.) on hydrolysis and esterification gives the tribasic ester (190–95°/3 mm.) from which, on Dieckmann's condensation and hydrolysis, gives this acid. The acid-chloride of this keto-acid condenses with magnesium-malonate ester. On hydrolysis it gives the methyl ketone (133°/3 mm.) and this diketone on dehydration gave the unsaturated tricyclic ketone (130–35°/3 mm.) isomeric with the one described before, with respect to the double bond.

The condensation product from cyclohexanone and unsaturated bromo-ester on hydrolysis gives the unsaturated keto-acid from which in an identical way the methyl ketone (140–45°/5 mm.) is obtained. This diketone on dehydration is expected to give the doubly unsaturated tricyclic ketone. On reduction of the double bond adjacent to the carbonyl group and of the carbonyl group according to Clemmensen, a tricyclic unsaturated hydrocarbon is available. It is possible to introduce at the methylene group (so-called C_{17} -position of the steroids) in the cyclopentane ring a bromine atom with the help of N-bromo-succinimide. These methods are being extended with 9-methyldecalone.

My grateful thanks are due to the National Institute of Sciences of India for an I.C.I. Research Fellowship in Chemistry.

Name of Research Fellow .. Dr. R. N. Singh.

Subject of Research .. Algology.

(December, 1945—November, 1948.)

Under the tenure of the Imperial Chemical Industries (India) Research Fellowship, from December 1945 to November 1948, the Research Fellow, *Dr. Rama Nagina Singh, D.Sc.*, has investigated a number of problems on Algology and related subjects. The results of these investigations, besides being of purely scientific and academic interest, have in many cases proved to be of immense practical and economic importance, in so far as they promise to add materially to the agricultural wealth of the country. Special mention may in this connection be made of the enormous rôle played by the terrestrial Blue-Green Algae in the economy and conservation of the soil with reference to its nitrogen, organic matter, moisture and also the prevention and control of soil surface erosion. The amount of nitrogen added by these micro-organisms growing in the rice-fields, 'Usar' lands and grasslands of Northern India, has been estimated to be of the order of 10–15 lbs. per acre annually. In view of the surprising results it has been considered legitimate to conclude that the recuperation of nitrogen and the subsequent maintenance of fertility of the land with particular reference to the above-mentioned habitats is mainly due to the activity of the Blue-Green Algae. It is here in the tropics or subtropics that it is clearly demonstrated for the first time that the Blue-Green Algae growing in and on the surface of the soil play an equally important (or may even be greater) rôle in the economy of the soil as compared to other soil micro-organisms like the species of *Azotobacter* and *Clostridium*. On account of their peculiar metabolism the Blue-Green Algae are the only living organisms which can utilise and

fix both the carbon and the nitrogen from the atmosphere directly. Soil surface Blue-Green Algae have been collected and studied from this point of view from the Provinces of Bihar, U.P., Delhi, Rajputana, Central India and Bombay, from different soil and rock types and geological formations. Their relative abundance, value and importance in conservational processes have been assessed together with data on their ecology, growth-relations, physiology and biochemistry. *Aulosira fertilissima*, *Nostoc commune* and *Porphyrosiphon Notarisii* in different habitats stand out as the most promising forms along with their co-dominants, *Anabaena fertilissima*, *A. variabilis*, *A. ambigua*, *Cylindrospermum gorakhporensis*, *Stigonema minutum*, *Mastigocladus laminosus*, *Schizothrix aurantiaca*, *Microcoleus chthonoplastes*, *Scytonema ocellatum*, *Campylostroma lahorensis*, etc.

The physiological bases for drought-resistance in some of the above-mentioned terrestrial and subaerial Blue-Green Algae have been investigated. The data thus obtained have led to the formulation of a working hypothesis on the mechanism of drought-resistance in plants in general. It has been suggested that drought-resistance of a plant depends upon its protoplasmic factors, i.e. the colloidal properties of its cell protoplast, key to all physiological processes. The Myxophyceean cell, on account of its simplest organisation in the plant kingdom, has proved to be a very favourable material for the study of cell physiology. In the light of the results obtained here some of the orthodox opinion about the absence of starch and pyrenoids in these algae needs revision. Besides, these plants have also been found to be subjected to a natural process of vernalisation, which consists in alternate soaking and drying of the material due to intermittent rainfall. It further adds to their drought-resistance capacity.

The Indian water-bloom algae have been studied in detail from both ecological and economic point of view. Unlike the claims made by the algologists of countries like America, Africa, etc. the Indian water-blooms, although involving the same forms, have never been found to be poisonous and fatal to cattle and human beings. This has been proved by interesting experiments in the laboratory. On the other hand, the bloom algae have been found to be very useful as a source of organic manure. Their manurial value has been investigated with sugar-cane crop in pot cultures. The different forms involved are the species of *Microcystis*, *Anabaena*, *Anabaenopsis*, *Wolleea*, etc., which contain from 7 to 18% of nitrogen besides a fairly good amount of phosphorus and calcium. These algae have also been proved to be useful as starter for compost manufacture. A number of limnological problems in relation to inland fisheries of some local rivers and lakes have been studied besides the investigations on the manuring of nursery ponds in order to increase their phytoplankton content. The Blue-Green Algae have proved to be better food for fishes in comparison to the Green Algae on account of their high nitrogen content. Consequently, organic fertilisation has been suggested. The biological productivity of a number of temporary ponds has also been investigated in relation to annual output of organic matter and on drying, the value of their bottom mud as manure has been envisaged. In this connection some field trials have been made with wheat and barley and a definite increase in yield has been found.

An investigation of the Blue-Green Algae growing on the roof of buildings which cause their sweating and ultimately lead to the damage and fall of the ceilings, a problem of great importance in building engineering, has been made. The plants responsible for this nuisance are able to do so on account of their great capacity to retain moisture due to copious secretion of mucilage and they also, in many cases, have been found to be actually concrete and cement boring. Control measures for these algae have been worked out and the methods suggested are both mechanical and chemical. The latter is preferable and involves the application of copper sulphate in different proportions and concentrations according to the extent of algal growth actually encountered.

The biology, ecology, cytology and life-histories of a number of important algal types belonging to the Chlorophyceae and the Myxophyceae have been investigated. Notable amongst these are the studies on *Gonium pectorale* var. *myxophyticum* var. nov., *Dropanulidia indica* sp. nov., *Stigeoclonium amoenum*, *Fritschella tuberosa*, *Mastigocladus laminosus* and *Calothrix brachytrichoides* sp. nov. The investigations on the life-histories of *S. amoenum*, *D. indica* and *F. tuberosa* have materially added to our knowledge of the life-histories of Cheatophorales in particular and of Chlorophyceae in general. These studies have also elucidated the evolution of land-habit and land plants. They have also helped in the understanding of phylogenetic interrelationships between important species, genera and classes of algae.

Some important ecological studies of the algal flora of the radioactive hot springs of Rajgir (Bihar), the subaerial algae of Nalanda (Bihar), and those of Mt. Abu (Rajputana) have also been completed.

In conclusion, the Research Fellow takes this opportunity to express his great indebtedness to Prof. Y. Bhāradwāja for his kind guidance and criticism throughout the course of these investigations.

Name of Research Fellow .. Dr. R. V. Sitholey.

Subject of Research .. Study of fossil plants with reference to their structure and affinities in relation to questions of plant evolution and palaeogeography.

Saline Series of the Salt Range, Punjab.

A paper entitled 'Microfossils from a kerogen shale of the Saline Series in Khewra gorge, Salt Range' has been published (*Proc. Nat. Acad. Sci. Ind.*, **16** (2-4), 220-225, 1947. With one Plate). A woody fragment and some diatom-like bodies are described from a combustible kerogen shale collected by Professor B. Sahni, F.R.S., at Anderson's locality in the Khewra gorge. The woody fragment, with simple pits uniserially arranged, doubtless belongs to a highly evolved vascular plant, probably an angiosperm. The diatom-like bodies are made up of calcareous matter, and were most probably formed by the secondary infilling of diatoms by calcium carbonate. Both the types of microfossils suggest a post-Cambrian age for the shale.

Fossil plants from the Nammal gorge, W. Salt Range.

This collection, of which only a part has so far been worked out, was made by the author in October 1946 from the Nammal gorge, about 2½ miles north-east of Musa Khel in district Mianwali, West Punjab. Material was collected from the Middle Productus and Upper Productus Beds of Permian age, from the Kingriali Sandstone Stage (? Triassic), and from the Variegated Stage (Jurassic).

Kingriali Sandstone Stage.—Specimens of a yellowish brown sandstone with carbonaceous lamellae were collected from a bed lying between the Ceratite Beds and the Kingriali Dolomites. On maceration the carbonaceous bands have yielded a large number of excellently preserved cuticles. Some of these cuticles show gymnospermous characters. Some purple coloured sandstones from this stage contain minute plant fragments.

Variegated Stage.—The plant-remains obtained from these beds are: Bennettitales (*Otozamites* spp.), Coniferales (? *Paytopyllum* sp.), and Cyatheaceae (*Protopteris nammalensis* sp. nov.). Of *Otozamites* there appear to be two different species separable by the characters of the pinnae and their arrangement on the rachis. The coniferous shoot has yielded well-preserved cuticles showing the stomata arranged in longitudinal rows on the abaxial side of the leaf, surrounded by usually five thick-walled subsidiary cells.

A paper entitled '*Protopteris nammalensis* sp. nov., a Jurassic cyatheaceous tree-fern from the Salt Range, Punjab' has been printed (*Proc. Nat. Inst. Sci. Ind.*, **15** (1), 1-10. With 3 Plates and 9 Text-figures). The genus *Protopteris* has been recorded for the first time from India and, as far as we know, from Gondwanaland. It has so far been found in Cretaceous and Tertiary rocks only and this is probably the first report of its occurrence in the Jurassic. The present discovery extends the distribution of the Cyatheaceae in India during the Mesozoic period to the north-west. The specimen is a cast of a stem covered all round with rhomboid leaf bases. The leaf trace is composed of a single bundle of horseshoe shape with the ends probably incurved. The lower part of the trace shows sinuosity.

Mesozoic gymnosperms and other plant remains from the Salt Range, Punjab.

This joint work with Professor Sahni is based on material collected by Dr. E. R. Gee and Mr. N. K. N. Aiyengar of the Geological Survey of India. Three new species of the Bennettitalean genus *Otozamites* (*O. pecten*, *O. oblongus* and *O. sakseurensis*) are described. The other fossils dealt with are *Brachyphyllum*, a coniferous shoot of which three species have provisionally been designated as A, B and C; *Podozamites* spp. and a number of other *plantae incertae sedis*. In nearly all the cases the specific determinations have been based on the structure of the cuticles as well as the gross features of the specimens. Good transfer preparations have in several cases facilitated the anatomical study of the fossils. The three species of *Brachyphyllum* are most probably new.

Name of Research Fellow .. Dr. M. K. Subramaniam.
Subject of Research .. Cytogenetics of Yeast.

(March 1, 1947—March 1, 1948.)

Introduction.

The work on 'Cytogenetics of Yeasts' was started in December 1944. During the years 1945-47 seventeen new strains of Brewery Yeasts and six new strains of Distillery Yeasts had been produced. Naturally, the work as an Imperial Chemical Industries Research Fellow was a continuation of the previous work. The stability of the strains had to be investigated.

Chromosome Constitution and Giant Colony Characters.

With the above end in view, a correlation between giant colony characteristics and chromosome constitution of the various strains was attempted. It was thought that if such a correlation

was possible, it would simplify studies on the stability of the various strains. The results are very encouraging. It appears that changes in chromosome constitution do produce changes in the characteristics of the giant colonies. It is possible to identify particular strains by their characteristic giant colonies. The resemblance thus is not confined to their top or bottom fermenting character alone. The similarity between colonies of known and unknown chromosomal constitution is striking and hence should be of considerable significance since the same chromosomal mutation could be produced by diverse agencies.

Causes for Confusion in Yeast Cytology.

For the past five decades our knowledge of the cytology of yeasts has remained in a confused state. The causes for the above state of affairs were analysed and it was discovered that most of the confusion could be traced to the fact that previous investigators used fermenting cultures for their investigations. The yeast is unique in that it can grow or ferment. Logically, therefore, the behaviour of the nucleus during aerobic growth alone is comparable to that of embryonic cells in higher animals and plants. Extensive details regarding handling of yeasts for cytological investigations have been embodied in a paper entitled 'Studies on the Cytology of Yeasts. III. Technique of handling Yeasts for Cytological Investigations'.

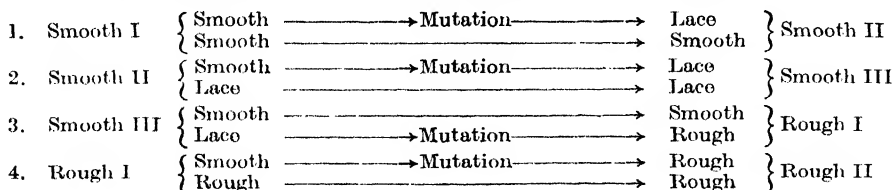
Endopolyploidy in Yeasts.

A fermenting yeast cell is comparable to a gland cell of higher animals. Investigations on the cytology of glandular cells have revealed that secreting cells become endopolyploid to meet the new physiological demands. A similar state of affairs has been demonstrated in fermenting yeast cells also. The usual fate of endopolyploid cells being death and disintegration after varying periods of activity and since in the final stages of fermentation, excepting for a negligible percentage, most of the cells should be endopolyploid, the necessity for the rejuvenation of the cultures after each fermentation would at once become apparent. This may explain why continuous fermentation without rejuvenation is almost a virtual impossibility.

Reverse Mutations in Yeasts.

Observations on a continuous but overlapping series of giant colonies of the two chromosome control strain indicated a seasonal change in the characteristics of the giant colonies. In the months of September to March the colonies were smooth with radial folds and with (Smooth II) or without (Smooth I) concentric striations near the periphery. In March-April there was a sudden change. The colony first developed innumerable prominent radial and concentric striations in the outer half giving it a lace-like texture (Smooth III) and then gave a colony which had a rough appearance owing to the presence of minute powdery granulations on a lace-like sculpturing. The rough colonies themselves were of two types. While in Rough I the centre was smooth, in Rough II the entire surface of the colony had a rough sculpturing.

A complete, spontaneous and orderly reversal was observed in September-October. The Rough I gave rise to Smooth III, Smooth II and Smooth I types. Since the cultures were kept in the vegetative condition and grown at room temperature, it appears that sudden changes in temperature bring about 'Mass Mutations' or 'Upheavals'. If we assume the existence of three alleles, viz. Smooth, Lace and Rough, the five types could all be classified.



The rarity of the Smooth III condition led to the suspicion that the lace gene may be an unstable one and that it may be relatively stable only in the homozygous condition. It appears, therefore, that multiple alleles exist for the locus determining surface sculpturing. The cells having different allelic combinations have different rates of growth during the various seasons. Thus, even if a culture is composed of cells of different gene constitutions, the Smooth I type completely eliminates the others by its relatively superior growth rate during the cold season in Bangalore.

The mutability demonstrated above leads one naturally to the problem whether different genes controlling fermentation of particular sugars are as mutable?

Mode of Action of some Genes in Yeasts.

If, as is possible, a number of genes control the different steps of fermentation of any particular sugar, then mutation of any one of them may affect adversely the fermentative ability of the strain. The genes responsible for fermentation should in all probability be ones having very low mutation frequencies. *Further, the fact that fermenting cells are endopolyploid renders it probable that the above may be balanced genic combinations which function properly only when duplicated above a particular stage of endopolyploidy.*

Publications.

1. Endopolyploidy in Yeasts. *Curr. Sci.*, **12**, 83-84, 1947.
 2. Studies on the Cytology of Yeasts. II. Induction of Polyploidy and Heterochromatin. *Proc. Nat. Inst. Sci. India*, **13** (3), 129-139, 1947.
 3. Is the Macronucleus of Ciliates Endopolyploid? *Curr. Sci.*, **16**, 157-158, 1947.
 4. (With B. Ranganathan.) Chromosome Constitution and Giant Colony Characteristics in Yeasts. *Proc. Nat. Inst. Sci. India*, **14** (6), 279-283, 1948.
 5. Studies on the Cytology of Yeasts. III The Technique of handling Yeasts for Cytological Investigations. *Proc. Nat. Inst. Sci. India*, **14** (7), 315-323, 1948.
 6. Studies on the Cytology of Yeasts. IV. Endopolyploidy in Yeasts. *Proc. Nat. Inst. Sci. India*, **14** (7), 325-334, 1948.
 7. Reverse Mutations in Yeasts. *Proc. VIIth Internat. Cong. Agr. Ind. Paris*, July 1948.
-

**SYMPOSIUM
ON
MULTI-PURPOSE RIVER PROJECTS IN
INDIA'S NATIONAL ECONOMY**

PREFATORY NOTE

The Council of the National Institute of Sciences of India, at their meeting held in January, 1950, decided to hold a Symposium on *Multi-purpose River Projects in India's National Economy* on the occasion of the Ordinary General Meeting of the Institute to be held in Calcutta in August, 1950. A Committee, consisting of Dr. B. C. Guha, Dr. S. L. Hora and Dr. W. D. West (*Convener*), was appointed to organize it. The subject of the Symposium is of vital interest to India and the organizers spared no pains to ensure the participation of experts on various subjects to be dealt with under the Symposium. It is a matter of deep satisfaction that the response to the invitation was very generous. The organizers wish to express the thanks of the Institute as well as their own to the contributors of papers initiating discussions on different topics. They also avail themselves of this opportunity to thank all those who took part in the discussion and submitted their comments for inclusion in the *Proceedings*.

On October 24th, 1950, Sardar Vallabhbhai Patel delivered an illuminating Address at Delhi to the Central Board of Irrigation, and the Members of the Committee, in view of its relevance to the subject-matter of the Symposium, decided to include the last two paragraphs of the Address as an Appendix to the Symposium. Another thought-provoking article entitled 'The Challenge of Multi-purpose Projects: Need for reshaping India's Agrarian Economy' by Mr. S. K. Dey, Secretary, Agriculture and Irrigation Departments, Government of West Bengal, appeared in the *Statesman* of December 9, 1950, but owing to shortness of time it could not be included in the Symposium Number, but is referred to here to facilitate reference in future.

S. L. HORA,
Editor of Publications.

CALCUTTA,
15th December, 1950.

INTRODUCTORY SPEECH

By B. C. GUHA, D.Sc., F.N.I., Member, Damodar Valley Corporation, Calcutta.

SUMMARY

In the past, rivers have usually been treated for one or two particular purposes. Dams and barrages have been put up to supply irrigation water or/and to generate hydro-electric power. Sometimes embankments have been built to prevent floods. But the treatment of a river valley as a whole cutting across State boundaries and utilization of its water resources for multiple purposes in relation to the planned economic development of the entire valley is of relatively recent date. The Tennessee Valley Authority set an example when it harnessed the Tennessee river and its tributaries flowing through seven States, affording simultaneously the benefits of flood control, power and navigation and effecting a tremendous advance in the agricultural and industrial development of the Tennessee Valley by concerted measures in barely a decade.

The concept of the multi-facet development of a river valley by conserving and utilizing its water resources has now taken root in India. At present three major projects, the Damodar, Bhakra and Hirakud, along with a few others are under active execution. Among these, the Damodar project, which has been entrusted by the Government of India to a body called the Damodar Valley Corporation for implementation, may be taken as an illustration.

The Damodar river runs through the States of Bihar and West Bengal and its drainage area covers 8,600 square miles. The project consists essentially of constructing—

- (i) Eight dams on the Damodar and its tributaries with hydro-electric stations and two auxiliary plants with a total installed capacity of 240,000 kw.; the total controlled reservoir capacity would be 4.7 million acre-feet and should protect the valley from floods up to 1 million cusecs;
- (ii) A thermal power station, utilizing low grade coal, of 200,000 kw. installed capacity to even out the seasonal fluctuations of hydro-electric power and to provide, in combination with the hydro-electric system, firm power of 300,000 kw. capacity at 60% load factor;
- (iii) A power transmission grid covering 475 miles of 132 kv. primary line with necessary lengths of 66 kv. and 33 kv. secondary lines, and
- (iv) A barrage and a 90-mile long irrigation-cum-navigation canal with a system of distributaries measuring 1,553 miles in length and irrigating a million acres of fertile land.

The scheme is designed to provide flood control in the lower Damodar Valley, irrigation for the production of food and other crops, navigation facilities and power for the promotion of both industrial and agricultural development. The project provides for (a) soil conservation in the valley so as to retard the silting of the reservoirs and at the same time develop agriculture and forestry, (b) mineralogical survey of the valley and its adjacent areas to locate minerals which can be used for the development of industries for the production of insulators, refractories, aluminum, phosphatic fertilizers, etc., and (c) control of malaria. It is estimated that as a result of perennial irrigation and better agricultural practices 200,000 tons more of rice and considerable quantities of winter crops like wheat, pulses and potatoes would be available. The scheme also envisages the development of fisheries in the impounded waters and the irrigation channels. Facilities will be provided for recreation in the lakes which would cover a total area of approximately 170 square miles. Displaced people from this area will have to be rehabilitated. Attempts are being made to settle them on reclaimed land and raise them to a higher technical level of farming or a co-operative or collective basis, and also to introduce cottage or small-scale industries utilizing power which would be made available as a result of the scheme. The project is thus calculated to transform the life of the people of the Valley and its neighbouring areas to a marked degree in the course of half a dozen years.

The concept of the multi-purpose development of river valleys has now taken root in this country. For centuries past the treatment of rivers has been looked at in one or another aspect but rarely in integrated aspects. Thus, when a river was found to overflow its banks during the rains embankments were built for affording protection from flood. Rivers have been bridged to facilitate communication. Water from rivers has been canalized to provide irrigation. But hardly have the waters of a river been treated in a unified manner so as to promote a multi-facet co-ordinated development of the entire valley through which it flows. In recent years, however, particularly since the successful experiment of the Tennessee Valley

Authority in America, there has been a widespread recognition throughout the world that it is far more rational and economic to handle a river in all the aspects in relation to the resources and the needs of the river valley concerned. In the Tennessee Valley, for instance, dams have been built which perform the triple functions of controlling flood, generating electricity and facilitating navigation. The power development has led to a phenomenal progress of industries in the valley utilizing its natural resources. The aluminium industry, developed as the direct result of the Tennessee Valley project, helped the U.S.A. materially during the last war. Phosphatic fertilizer industries have been established in the valley which have had their effect on the productivity of the soil in the entire area. The food produced has been protected from spoilage by the development of refrigeration. In fact, laboratories established by the TVA have themselves developed and patented refrigeration devices for the preservation of food. In order to retard the silting up of reservoirs extensive afforestation has been resorted to in the valley, which, while giving long life to the reservoirs, controls soil erosion, produces timber and helps the navigation of the Tennessee River. At the same time, as malaria is often associated with the impounding of water, the TVA has an extensive programme of malaria control in the valley. Thus the results of the efforts of the TVA in promoting the co-ordinated development of the Tennessee Valley in relation to its industries, agriculture and health are manifest.

In India at present a number of similar multi-purpose projects in relation to river valleys have been initiated. The Damodar, Hirakud and Bhakra schemes, among others, are in active execution. The Damodar scheme may be taken as an example to illustrate the multi-purpose nature of the scheme in relation to the national economy of India. The Damodar is a notoriously destructive river which originates in the uplands of Bihar, flows through West Bengal and joins the river Hooghly below Calcutta. Due to deforestation in the upper valley and steady soil erosion, more and more silt and sand have been coming and depositing in the lower reaches of the Damodar raising its bed-level. This is aggravated by silt bars brought by the tides from the Bay of Bengal. The river, therefore, tends to have less and less capacity for carrying flood waters which naturally overflows its banks. A flood in 1943 had actually torn off the embankments of the left bank of the Damodar and washed away parts of the arterial railway and Grand Trunk Road from Calcutta to north-western India. When it was found that embankments failed successfully to resist flood the Damodar Flood Enquiry Commission was set up which recommended the adoption of the present scheme now under execution.

The Damodar river runs through the States of Bihar and West Bengal and its drainage area covers 8,500 square miles. The project consists essentially of constructing—

- (i) Eight dams on the Damodar and its tributaries with hydro-electric stations and two auxiliary plants with a total installed capacity of 240,000 kw.; the total controlled reservoir capacity would be 4.7 million acre-feet and protect the valley from floods up to 1 million cusecs;
- (ii) A thermal power station, utilizing low grade coal of 200,000 kw. installed capacity to even out the seasonal fluctuations of hydro-electric power and to provide, in combination with the hydro-electric system, firm power of 300,000 kw. capacity at 60% load factor;
- (iii) A power transmission grid covering 475 miles of 132 kv. primary line with necessary lengths of 66 kv. and 33 kv. secondary lines; and
- (iv) A barrage and a 90-mile long irrigation-cum-navigation canal with a system of distributaries measuring 1,553 miles in length and irrigating about 1 million acres of fertile alluvial soil.

The idea is to suitably store the rain water during the monsoon in the reservoirs formed by the dams so as to prevent floods in the lower valley and at the same time

to gradually release the water from the reservoirs producing hydro-electric power, irrigating a million acres of land and facilitating navigation from Durgapur, which is below Asansol, to Calcutta *via* the canal and the river Hooghly. In order to implement the project the Damodar Valley Corporation was set up by the Government of India somewhat on the lines of the Tennessee Valley Authority with rather similar terms of reference. The main object is the multi-purpose development of the Damodar Valley. Thus, along with this construction project steps are being taken to control soil erosion particularly in the upper valley by the usual practices of soil conservation, viz. terracing, contour ploughing, damming up rivulets, planting suitable grasses, gully-plugging, afforestation, etc. With regard to the utilization of power in the valley, which is rich in coal and several mineral resources, investigation has been undertaken by the Geological Survey of India in the valley and its surrounding area to locate useful minerals which could utilize the power and water that would be made perennially available as a result of the project for the development of suitable industries. Similarly, along with soil conservation practices initiated by the Corporation and the provision of water for irrigation, attempts are being made to improve agricultural practices through experimental and demonstration farms and make optimum use of the water available for the production of food and other crops. It is estimated that as a result of the project about 200,000 tons more of rice will be available and also large quantities of winter crops which together would be worth about 15 crores of rupees annually. There is also a great scope for development of industries for the production of insulators, fire-bricks, aluminium, calcium carbide, etc., utilizing the mineral resources of the valley. The development of fisheries in the impounded waters and irrigation channels is envisaged. The lakes formed will also provide facilities for recreation. Malaria control is an important feature of the project because large parts of the valley are malarious and there may be a tendency for malaria incidence to increase in certain parts as a result of the dam and irrigation project. The displacement of people from areas to be inundated raises the problem of rehabilitation which also offers opportunities for the initiation of co-operative or collective farming at a higher technical level and also the introduction of cottage and medium-scale industries utilizing power which would be made available fairly cheaply as a result of the project. All these co-ordinated developments based on this multi-purpose river project are calculated to raise the economic level of the people of the valley and its neighbouring areas to a significant degree in five to ten years' time and strengthen the national economy of India as a whole.

PRINCIPLES OF PLANNING

By KANWAR SAIN, I.S.E., Member (Designs) Central Water-power, Irrigation and Navigation Commission, New Delhi.

(Communicated by Dr. B. C. Guha, F.N.I.)

SUMMARY

Planning of river valley projects must be realistic and within limitations imposed by India's National Economy. It should be grouped into:—

- (a) Short range;
- (b) Medium range; and
- (c) Long range projects.

Once the construction of a project is taken in hand it must be completed within the shortest possible time.

Planning of multi-purpose river projects should aim at the fullest utilization of all potentialities of the natural resource. There should be no waste of any possible potential due to narrow regional considerations.

Each project must be able to pay its own way. We cannot afford to borrow from unborn generations. Each multi-purpose project should, therefore, be assessed as one integral whole from the point of view of its financial feasibility. Apportionment of cost between various purposes must be kept sufficiently elastic if such apportionment is considered necessary.

In phasing multi-purpose projects priority should be considered in the order of utilizable potential of each phase of the project; the ultimate total potential being kept in view in long-range planning.

There should be proper co-ordination and phasing of projects in the entire country with the object of making the best use of available resources of materials and for utilizing construction machinery and specialized staff from one project to another irrespective of the State boundaries in which any particular project may be located.

As far as possible one authority and one organization should be responsible for the development of a multi-purpose project in all its aspects.

CONTENTS

	<i>Page</i>
1. What is a Multi-purpose River Project ?	381
2. Functions of a Multi-purpose Project	382
3. Necessity for Multi-purpose Projects in India	383
4. Limitations imposed by India's National Economy	384
5. A Parallel from the United States of America	385
6. How does India Stand ?	387
7. Basic Principles of Planning	388
8. Stages of Investigations and Planning	388
9. Factors for Consideration in Detailed Planning	390
10. Criteria of Economic Justifiability	390
11. Power from Multi-purpose Projects	391
12. Allocation of Project Benefits and Costs	391
13. Co-ordination of River Valley Projects	393
14. Acknowledgments	393
15. Bibliography	394

I. WHAT IS A MULTI-PURPOSE RIVER PROJECT ?

In most instances a Multi-purpose River Project represents the integrated construction of two or more projects, each having a particular purpose or function. For reasons of economy or scarcity of sites these projects are combined and constructed at the same site and are planned, designed and operated to serve more than one function. Separately constructed, some of them might not be economically

justifiable. Constructed in combination, the savings result in making these component projects at least more nearly if not entirely justifiable.

Though a strict definition would exclude those projects whose planning, design and operation are controlled by a single function even though other benefits accrue as by-products; in general terms, however, any project planned and designed to conserve, control and regulate the flow in rivers and streams in order to utilize all the potentialities of this flow for the benefit of mankind may be called a multi-purpose river project.

The term 'Multi-purpose Project' lends credence to the very general, though frequently erroneous, assumption, especially on the part of the non-technical public, that with little or no increase in cost a given reservoir may serve several different purposes. For instance a common assumption is that a reservoir intended to be used in its entirety for flood control will always, incidentally and of necessity, create raw water power, for the development of which it is merely necessary to install pen-stocks and provide a power station. This assumption persists despite the fact that, in general, between successive floods, a flood control reservoir should remain empty.

A multi-purpose project may consist of a dam and other works; a series of dams; or a series of dams and other works designed and operated so as to perform efficiently more than one function in the field of water utilization and control.

2. FUNCTIONS OF A MULTI-PURPOSE PROJECT

A multi-purpose project may serve some or most of the following functions:—

- (i) Irrigation;
- (ii) Generation of hydro-electric power for low cost supplies to homes, farms, and industry;
- (iii) Flood control and navigation;
- (iv) Stabilized fresh water supply for Municipal and Industrial use;
- (v) Fish and wild-life protection and propagation;
- (vi) Recreation, drainage, pollution abatement and silt control; and
- (vii) Salinity repulsion in areas affected by ocean tides.

Other supplementary purposes of the project may be prevention of soil erosion, sedimentation control, sewage and industrial waste control and malaria control in tropical and temperate areas.

In most multi-purpose projects one or two functions are of major importance and are accorded priority in various phases of planning over other benefits obtained from the same project. For example, the United States Bureau of Reclamation considers irrigation of paramount importance in planning of multiple purpose projects, and nowhere in its policy-making legislation does the Bureau accord recognition to power production as a function superior to the use of water for irrigation. Similarly, the Army Corps of Engineers give priority to flood control in planning and other benefits are considered as secondary.

As an outstanding example of a truly multi-purpose project, I may cite the Central Valley Project in California in United States. The major functions of the project are:—

- (a) to provide for irrigation in the San Joaquin Valley and in the vicinity of Stockton and Fresno. Four canal systems have been built for the purpose;
- (b) to provide and supply power for industrial developments in the Sacramento area and also for pumping plants on the canal systems;
- (c) to provide protection against floods in the Sacramento River basin;
- (d) to make Sacramento River navigable by maintaining minimum required draft during the dry season;

- (e) to assure fresh water supplies to townships in the San Joaquin Valley and to control the invasion of the lower reaches of the Sacramento River by sea water.

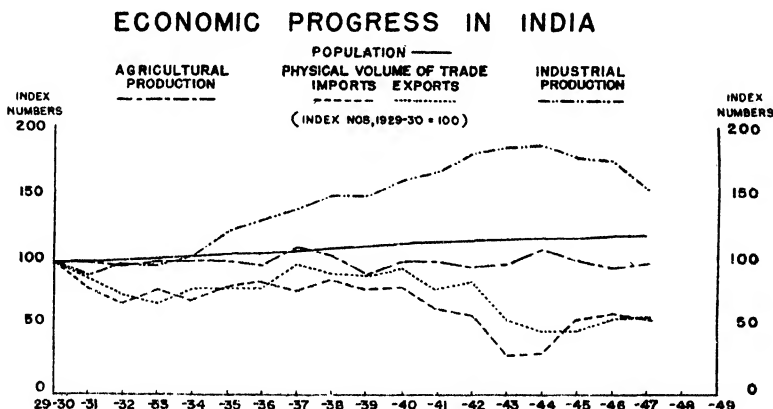
In India the Damodar Valley, Bhakra and the Hirakud projects may be cited as examples of multi-purpose projects.

3. NECESSITY FOR MULTI-PURPOSE PROJECTS IN INDIA

There has been a steady increase in population since the middle of the eighteenth century. The food production kept pace with the growth of population till 1930, when it began to lag behind. The author gave a warning to this effect in his paper 'Economics and Finances of Irrigation Projects' presented to the Punjab Engineering Congress in 1939. But wheat was then selling at two rupees a maund; nobody was starving. The warning fell on deaf ears. No action was initiated by Government, till the Famine Enquiry Commission in 1945 reported 'India before the war, was not self-sufficient in foodgrains, a small exportable surplus of wheat being offset by large imports of rice.'

The deficit of food in India in 1947-48 was 2.8 million tons. With the growing population the total deficit to be made up between 1948 and 1960 is estimated to be of the order of 9.5 million tons.

During the past three years India has been finding it difficult to export goods in sufficient quantities to pay for its large import needs without seriously depleting its foreign assets. In the summer of 1949 the difficulty became acute particularly due to devaluation of India's currency.



It will be interesting to have a bird's-eye view of India's economy in the last 20 years. An interesting graph of economic progress in India has been given opposite page 44 of Fiscal Commission Report, Volume I, 1949-50. This graph is reproduced above. While the country has greatly reduced its dependence on foreign sources of supply in certain consumption articles, e.g. in cotton textiles, matches, soaps, sugar, paper, cement, iron and steel and a few chemicals; the agricultural sector of the country's economy has remained stagnant. During this period there has been little increase in the total yield of agricultural crops or little change in the character of agriculture. Consequently, notwithstanding the increase of production in certain lines of manufacture; the market for industrial goods has remained restricted. During the last two decades India has been losing its share in world trade.

Today India has to depend on imports of foodgrains to feed its population and on imports of cotton and jute for its important industries.

The Fiscal Commission (1949-1950) have set out the following objectives and priorities of a short-term economic policy:—

‘Defence and basic and key industries stand in a special position. Excluding these the priorities should be as follows:—

- (i) Schemes for agricultural improvement especially irrigation and multi-purpose projects including minor irrigation works;
- (ii) Industries necessary for the implementation of the agricultural programme and construction and maintenance of irrigation and multi-purpose projects;
- (iii) Schemes for increased production in industries producing raw material and consumption goods;
- (iv) Manufacture and repair of the machinery and equipment needed by the industries in (iii).
- (v) Establishment of industries complementary to the industries in (iii) to (iv) and those that will increase external economies of these industries;
- (vi) *Pari passu* with the developments mentioned in (i) to (v):—
 - (a) encouragement of tertiary industries; and
 - (b) promotion of exports.’

Cheap power is an essential requirement for setting up industries particularly if our manufactured goods are to compete in the world market.

The main sources of power are and will continue to be fuels and falling water. Though in the United States about three-fourths of electricity is produced from fuels and only one-fourth from falling waters, reverse will have to be the position in India.

A question has sometimes been asked whether heat energy released by nuclear fission will not replace electric power generation in the next 10 or 15 years. This question deserves more space than is available here. ‘It should, however, be said that in the light of known progress and development in this most important new field, the use of nuclear heat power reactors will not be possible on any commercial scale in the near future. Existing and new installations using present heat sources will have served out their economic lives long before substantial use of atomic energy arrives. Careful analysis will show that the capital cost involved in utilizing the atomic fuel may be so great as to make its use economically unsound, even if the cost of the fuel should be a minimum. The problems involved in the preparation, handling, utilization, and disposal of atomic fuel are great. Unless they can be solved at lower capital costs than presently seems possible, there can be no early substitution by this new found fuel for coal, or even any supplemental use of it. Consequently development plans should continue unhesitatingly to utilize the present sources of energy.’

From these recommendations of the Fiscal Commission it will be seen that the highest emphasis has been laid on the development of irrigation and industries through multi-purpose projects. All other plans to make India self-sufficient in food and industry must follow and cannot precede these projects.

4. LIMITATIONS IMPOSED BY INDIA'S NATIONAL ECONOMY

Since the close of the last war, the Centre and the provinces have been feverishly busy preparing plans of development in almost every phase of national activity. The total estimated expenditure on the execution of these plans according to the rates prevailing in 1946 comes to nearly 3,500 crores of rupees.

On the basis of assumed total national income of Rs.4,000 crores per annum and the annual national savings at 5 per cent of the total of the national income,

the annual national saving would be of the order of Rs.200 crores. This would represent all the money that could be made available for annual expenditure on the Government as well as private projects.

Foreign investment has played a relatively small part in supplementing domestic goods production; indeed the sources of foreign capital practically dried up from the beginning of 1930's.

In the circumstances it is not surprising that there has been little increase in the over-all supply of goods and services available for domestic consumption of India's masses. In spite of the advance made in some lines of manufacture the deficiencies in the different sectors of economy still remain considerable and a great effort will be needed to make up the deficiency in agricultural and industrial production. A good deal of screening of our plans of development would be required in the context of our immediate needs. First things must come first.

The other bottle-neck for the speedy completion of river valley projects is the limitation of available materials of construction mainly steel and cement and of foreign exchange. It is evident that all the projects, Central and State, cannot be undertaken simultaneously and that these schemes must be adjusted to realistic possibilities.

It is bad economy to prolong the period of construction of a project longer than is warranted by its engineering considerations.

While construction should be limited to the available resources in materials of construction money and trained technical personnel, this should not be advanced as an argument for withholding or postponing investigations and general plans for effective development of rivers of India.

5. A PARALLEL FROM THE UNITED STATES OF AMERICA

The continental area of the United States comprises the basins of over 160 separate rivers, and the valleys of innumerable small streams, which flow east and west to the Atlantic and Pacific Oceans, southward to the gulf of Mexico and north to pass through Canada and reach Hudson Bay and the gulf of St. Lawrence. These rivers and their basins range in magnitude from coastal estuaries draining a few square miles, to the great Mississippi river, one of the longest river system in the world, which with its tributaries drains the entire inland basin lying between the Rockies and Appalachians, including over 40 per cent of the area of the United States.

With the increasing growth of the American nation the need for controlling, conserving and using wisely the resources afforded by the rivers became more and more evident. Problems and potentialities of the river basins, which were relatively of minor consideration in a sparsely settled agricultural country, became of foremost importance to a growing industrial nation.

The national character of these problems and potentialities was recognized progressively by the Congress of the United States. The authority of Congress to legislate with reference to navigable waters of the United States was definitely established in 1824. Cognizance of flood control as a problem of national interest was taken in 1879. It was in 1888 that Congress appropriated funds for surveys for determining the extent to which the arid regions of the United States could be reclaimed by irrigation and for selection of reservoir sites for the storage of water. Initial Reclamation Act under which the Federal Reclamation Activities are being prosecuted by the Bureau of Reclamation in the west of the 97th meridian was passed by Congress in 1902.

The Federal Power Act was originally enacted in 1920 in an initial effort to establish a degree of federal regulation over the development and distribution of hydro-electric power. Functions of the Federal Power Commission established thereby have been clarified and extended by subsequent Acts of Congress.

In 1925 the Congress had authorized the Secretary of War and the Federal Power Commission to prepare an estimate of cost of surveys of rivers of the United States 'with a view to formulation of general plans for the most effective improvement of such streams for the purposes of navigation and the prosecution of such improvement in combination with the most efficient development of the potential water-power; the control of floods, and the needs of irrigation'. An estimate of surveys required and their cost was submitted to the Congress in 1926. Surveys of essentially all the rivers of the United States were authorized in 1927 and 1928. The great majority of these comprehensive river basin surveys were completed by the Corps of Engineers during the ensuing 10 years period. With this mass of factual information available, Congress was able to draft and pass 'Flood Control Act, 1936' which established flood control throughout the country as a Federal activity and authorized a large number of specified flood control projects to be prosecuted at an estimated cost of 310 million dollars.

The comprehensive river basin surveys referred to above not only formed the factual basis for general Federal flood control legislation, but were of basic value to the Congress in 1933 when the Tennessee Valley Authority was established by legislative action; as the engineering plans for control and use of the waters of the Tennessee river and its tributaries which have been developed by T.V.A. were essentially based on these comprehensive river basin surveys. Extensive use has been made of these surveys by many States and local agencies concerned with water resources planning.

As a result of continued studies over a period of about 25 years, comprehensive plans of improvement and development for all the essential rivers of the United States are now available.

The grand total cost of comprehensive plans for conservation and use of the water resources of the United States including work completed and underway may be divided among the following functions of the plan approximately as follows:—

	\$	Percentage of total.
Flood control	12,295,200,000	21.29
Navigation	6,233,100,000	10.83
Hydro-electric power	24,086,900,000	41.89
Irrigation	8,681,600,000	15.10
Drainage	375,400,000	.65
Watershed treatment	4,012,000,000	6.98
Pollution control	1,365,800,000	2.37
Preservation of Fish and Wild-life and Recreation	456,200,000	.79
Total	57,506,200,000	

The cost of completed parts of the overall plan of improvement is estimated at 4,780 million dollars. The cost of projects under construction by the Federal Government in co-operation with local agencies in all parts of the country is estimated at 4,593 million dollars. Projects definitely planned to meet the needs of the immediate future is estimated at 18,981 million dollars. Many of these projects have present economic justification. This part of the overall plan includes most of the projects necessary to provide a well-rounded programme of river basin development for the next 20 or 25 years. Any plan of this magnitude could be accomplished in an effective manner only if the planning and constructing agencies of the Federal Government can proceed under an orderly programme which continues at a fairly uniform rate over a period of years.

In addition to the foregoing, plans have been prepared looking towards ultimate development of water resources which may prove justified over a long range future.

This plan which may serve as a guide to proper long range development are set forth to give an approximation of the probable cost of full water resource development at 29,153 million dollars.

These figures are based on the comprehensive plans prepared according to major geographical regions of the United States.

Accomplishment of the complete programme of development is a task of great magnitude. Nevertheless it is believed by the engineers in America that over a period of time it is entirely practicable and within the range of demonstrated capabilities of the nation. For example the appropriations by the Congress for the fiscal year 1949 for public works of the type in question will aggregate to more than a billion dollars. On this basis the programme will be accomplished within the lives of the present generation. The grand total cost should also be considered in relation to the work completed and under-way. This will indicate that with the completion of works now under construction about 16 per cent of the total projects will be completed. As one considers that practically all the work completed has been accomplished in the past 40 years and that all the work under construction was initiated during the past 10 years, a proper time perspective for the overall plan of improvement would be obtained.

This picture of the problem of utilization of the water resources of the United States has been made possible by the availability of the river basin surveys which were authorized by the Congress in 1925. It required a full organization of 10 Divisions and 41 Districts covering the entire United States to keep the plans up to date and co-ordinated with the plans and activities of other federal and local bodies.

It is believed that the figures given are correct within the limitations involved in estimating for long range future projects. The benefits and advantages which will accrue from the long range programme of water resource development will far exceed the cost. In fact sound programme of river basin development is considered as essential to the survival of the nation.

6. HOW DOES INDIA STAND ?

No such overall plan of development of river basins in India has yet been prepared or even attempted.

The Central Waterpower, Irrigation and Navigation Commission has collected all available relevant data for projects under investigation by the Government of India, the States and other bodies. This information has been published in a book entitled 'Data for River Valley Projects in India'. These projects by no means cover all the river basins. Yet the information in the Data Volume gives a good picture for our planners and financiers.

There are in all 160 projects under consideration of which 46 are under construction—estimated to cost Rs.371 crores; 53 are in advanced stage of investigation and ready for execution—estimated to cost Rs.530 crores and 61 are in initial stage of investigation—estimated cost Rs.378 crores.

The total expenditure involved in the overall plan will be Rs.1,279 crores, of which 13.1 per cent will be in dollars, 8.8 per cent in sterling and altogether Rs.279 crores or 21.9 per cent in foreign currency. The above expenditure will bring 31.12 million acres of additional area under irrigation, giving 10.3 million tons of additional food. It will give 8.5 million kw. of additional power, beside other advantages.

Compare the above figures with the cost of river valley projects under consideration in U.S.A.

Even with all the projects given in Data Volume only 20.8 per cent of the available waters of Indian rivers will have been utilized for irrigation and power. This will indicate not only the necessity for immediate construction of projects already under consideration, but for preparation of further projects.

About 78 per cent of the cost of river valley projects can be broken down to so many man-hours of which about 40 per cent will be spent at the site of the project and 60 per cent at other places for manufacture of materials, transportation and administration.

Cost of these projects should, it is suggested, be broken down in man-hours, of which so many are idle at present in India. The Planning Commission and the engineering profession should bend their energies in utilizing these idle man-hours for the development of River Valley Projects in the country.

7. BASIC PRINCIPLES OF PLANNING

A multi-purpose project should aim at the optimum and the most efficient water-shed development and utilization of the available resources of the valley. There should be no waste of any possible potential due to narrow regional considerations. The planning, design, size and operation of the various structural units and the reservoirs should be such as to satisfy the demands, though sometime conflicting, of all the designated functions of the project. In order to avoid serious conflicts in operating policies, it is advisable that the primary operating purposes of each unit are clearly defined at the planning stage. Also it is extremely desirable that all potentialities of the proposed project be carefully analysed to avoid costly duplication or reconversion in the future.

The feasibility of a project should be investigated from economical and structural points of view. The construction of a project should avert shortages in food and raw materials for industries. It should also be responsible for increased employment and higher standard of living.

While determining the possible and the required capacities of reservoirs and sizes of structures, the planners have to rely on many uncertain factors, especially the hydrological data. The best approach is by a process of elimination of the uncertain factors. It is a sound principle to use the reliable observed data in the first place and to resort to empirical solution as the last alternative.

Each project should be a good investment. It should not be a burden to the unborn generations. It should produce benefits that cannot be obtained at a lesser cost by some other means. Stress must be laid on the observation of the most stringent economy. There may be a tendency to make structures unnecessarily more expensive if the project is entirely or heavily non-reimbursable, i.e. if the project is not expected to repay the cost from the earnings.

Self-liquidating multi-purpose projects are the most favoured from the financial angle. The cost of the project and the repayment policies should be such as to make possible the maximum return to the government on its investment, the lowest cost to the tax payers, and the lowest rates to the users of water, power and other benefits.

8. STAGES OF INVESTIGATIONS AND PLANNING

Investigations and planning have to pass through several stages, before the ground is ready for detailed planning. Many engineers fail to make a proper distinction between these stages with the result that considerable amounts of time and money are spent on projects, which have ultimately to be dropped for engineering or economic reasons. The relative importance of these stages has been briefly discussed in this paragraph.

When investigations of a particular project are initiated, the full data and studies necessary to support adequately and conclusively the prescribed objective of investigation should be carried out with the minimum expenditure of time and funds.

Investigations conducted prior to authorization of projects should be carried on to such a point and in such detail only as is necessary to determine whether the project under investigation has engineering and economic feasibility. When feas-

ibility becomes apparent and authorization may be anticipated, investigations should be directed towards the requirements of a project planning report. In a similar manner, when infeasibility becomes apparent, pre-authorization investigation should be continued only to the point necessary to show infeasibility under existing conditions.

Pre-authorization investigations must be terminated at a reasonable point. On large projects, seasoned engineering, hydrologic and economic judgment and the best available safeguards for the reliability of results, necessarily, must be substituted for the finite and very detailed pre-authorization investigations. More detailed costly investigations, which are generally needed, should be scheduled immediately to follow authorization.

A very large project may generally involve policies peculiar to itself. These must be considered in the light of particular needs and circumstances. Where reasonable doubt exists as to feasibility of major features, it is necessary to carry out sufficient investigations to make preliminary plans and estimates, reasonably firm for obtaining authorization. Minor features may need to be investigated only after the reconnaissance study gives tangible form and substance to the scheme.

Investigations should be sufficiently complete so that the total estimated cost of the contemplated project will be known with reasonable accuracy but with the expectation that further and more detailed investigations might readily be expected to change the estimate within certain limits and to shift the distribution of benefits and cost among the individual features of the project.

It is not possible to outline a programme of potential developments for the greatest good to the greatest number of people in any area until the task of comprehensive planning is viewed from a basin-wide perspective. It is a requisite in all planning investigations that the area be looked at from a basin point of view in order to assure that a truly comprehensive picture is obtained. The possibility of trans-basin diversion may be kept in view where available water supply in a basin is inadequate to meet the possible development within physical limitations. With an inventory of all potentialities, it is possible to outline a comprehensive plan for the development of the natural resources of the basin.

Existing project and reconnaissance investigations should be considered as a start towards the basin planning. These investigations form an integral part of a basin investigation and should be incorporated into the general plan. They are supplemented by additional information where required.

After the reconnaissance investigations indicate that there are definite development potentialities which are consistent with overall basin plans, the programme of investigations may proceed to establish firm information for authorization and construction appropriations.

After a project or part of a project has been authorized and appropriation has been made available for its construction, it has to pass through two more stages before detailed planning can be taken in hand:—

- (a) Review of previous planning investigations.
- (b) Preconstruction or detailed investigations.

The review of previous planning investigations will depend upon two factors:—

- (i) the length of time which has elapsed since these investigations were made and;
- (ii) the availability of employees who participated in the initial studies.

When the above review clearly indicates that there are no basic obstacles either in the economic or engineering features of the project, intensive pre-construction investigations are made to permit preparation of the so-called 'Definite Project Report', before final plans and specifications are prepared for letting out construction contracts. Authorization is pre-requisite to the initiation of pre-construction

investigations and the preparation of construction designs and specifications for any particular project.

It is on the completion of pre-construction investigations that a 'Definite Project Report' which presents factual data and findings of these investigation negotiations and studies is prepared setting the field for detailed planning.

9. FACTORS FOR CONSIDERATION IN DETAILED PLANNING

After the project has been judged feasible the following factors should be considered in detailed planning:—

- (a) *Compromise necessary between the various functions for reservoir capacity design.*—This compromise should be based on the relative values involved.
- (b) *Comparison between costs and benefits.*—If the project has to be self-liquidating and paying, it is necessary to follow the rule that 'every investment should earn a rate of return commensurate with the risk involved'. This should be worked out for each phase of the project taking into account the utilizable potential of each phase.
- (c) *Determination of the most economical and suitable reservoir capacity for a particular site.*—For a reservoir site there are two values of capacity, the upper and the lower within which range, the benefits are more than the cost. Within these two limits there is one value of capacity at which the ratio of benefits to costs is a maximum and there is another value of capacity at which the difference between the benefits and cost is the maximum. The reservoir capacity should be designed between these two latter values.
- (d) *Comparison between a single large reservoir on the one hand, and various smaller ones on the other.*—Possibility of better regulation, better silt storage and ample capacity by providing smaller reservoirs instead of single large ones must be given due consideration. In certain cases big reservoir sites may be non-existent or impracticable.

10. CRITERIA OF ECONOMIC JUSTIFIABILITY

For a long time the financial criteria for the feasibility of a river valley project was that it should pay a return of 6.0 per cent in the 10th year after completion of the project on the sum-at-charge which is defined as capital cost plus cumulative interest minus cumulative net revenue.

The author of this paper raised a voice against this criterion in 1939 for the first time. As a result of several successive efforts mainly by Shri A. N. Khosla the minimum return has been reduced from 6.0 to 3.75 per cent.

It has been argued a number of times that there are several kinds of benefits which do not directly accrue to the exchequer. The criteria of economic justifiability should be applied in addition to the financial criteria. After all it is net gain in some form which measures the extent by which the national wealth is increased by reason of a multi-purpose project. In general practice the economic justification of multi-purpose projects is sufficiently demonstrated in the ratio of tangible benefits to cost. This ratio should be greater than unity and in some doubtful cases should be substantially greater than unity, say 1.25 to 1.50.

If in the case of a multi-purpose project which in its entirety has an acceptable ratio of benefit to cost, the average annual cost apportioned to a given primary component exceeds the criterion ratio which would be acceptable in relation to benefit, it is permissible to reduce the allocation of cost against that component and any other component in like status.

11. POWER FROM MULTI-PURPOSE PROJECTS

Where feasible, electric power generated on the project is a working and paying partner of irrigation. The importance of power in defraying the costs of a project will be evident from allocation of costs to different purposes. For profitable development it is advisable that the dams be designed with a power output, present and future, that fits in with the power resources and demands, present and potential, of the area to the very best advantage. The new systems should be planned to include the existing transmission systems to avoid wasteful and irrational duplication of facilities. Formation of power grids and co-ordination with other generating stations, both hydro and thermal, should be kept in mind during the planning stage.

Development of power resources and utilization of those resources involve a broad overall planning and considerations of many complex engineering and economical studies. The overall project development must include proper consideration of power development to assure optimum development and utilization of power consistent with other prior uses of water.

In the study of inter-connection between basins and the transmission of power to industrial areas it is necessary to prepare a special analysis of the power features including not only the generation and transmission of electric energy but also co-ordination of numerous power plants through inter-connected system and a study of market trends. Operation of a grid system must be flexible and subject to power adjustment to meet the constantly changing conditions. A well-designed and efficient network generally will 'deliver power and energy to the various load centres; provide two-way service to all important points; interconnect with neighbouring networks; and constitute an effective link in the regional power system'.

Two systems of marketing power are followed in the United States by Government agencies producing power from multi-purpose projects. The Bureau of Reclamation sells project power wholesale to the utility companies and distribution agencies, with preference to Municipalities, Public Corporations and to Co-operative and other non-profit organizations. In other areas regional authorities are established which are responsible for distribution of power to all the consumers. It has been found that the experienced selling organizations of the established companies can market the project power more efficiently to the greatest number of people.

On the average it has been estimated that for every 100,000 kw. of installed hydro-power, the capital expenditure required for generation of power along with the expenditure on other components of the multi-purpose project, cost of transmission and of industrial plant for utilizing this energy would be of the order of Rs.100 crores. This gives a capital requirement of about Rs.10,000 per kw. of installed power plant capacity. This would give an approximate measure of the capital required for utilization of power and would have an important bearing on the rate of utilization from a project.

12. ALLOCATION OF PROJECT BENEFITS AND COSTS

Allocation of benefits are made usually according to the importance of the various functions of the project considered in planning. Operation policies are also formulated for giving top priority to various functions in the same order. The allocation of costs of a project is, however, made in such a way that by-products like commercial power may have to pay more than their proportional share of benefits.

A combination of various allocation theories is used to determine the proper share of costs that could be assigned to each of the beneficiaries.

In the first place 'Ceiling' and 'Floor' allocations are fixed; the second step is to decide upon the practicable allocations. Floor allocations represent capital directly assignable to the several functions or uses of the project. Ceiling allocations are the values attributable to the project features as determined principally by the

lesser amount representing the estimated cost of providing corresponding services from alternative structures or the capitalized values of the annual benefits produced. 'Proportionate use' allocations, represent floor allocation plus allocation of joint facilities on an 'estimated use' basis to the several functions.

It will be interesting to give an example of allocation of benefits and costs for the Central Valley Project in California:—

(a) *Proportionate use.*

	Per cent.
Irrigation	53.8
Power	33.2
Navigation	6.8
Flood Control	5.3
Municipal and Industrial	0.9
National Security	0.0

(b) *Proportionate repayments.*

Irrigation	33.3
Power	48.5
Navigation	5.0
Flood Control	8.6
Municipal and Industrial	3.4
National Security	1.2

The importance of electric power in making a multi-purpose project feasible can be judged from the examples of the following Bureau of Reclamation projects:—

(a) *Hoover Dam.* The power it generates will repay 90 per cent of the cost of the project with interest.

(b) *Columbia Basin Project, Central Valley Project.* Power will repay more than 50 per cent of the cost of the project.

(c) *Parker Dam, Davis Dam, and Fort Peck Dam (Corps of Engineers).* On these projects all construction costs will be borne by power.

On all the Bureau of Reclamation projects under construction on January 1, 1942, power revenues are expected to pay 58 per cent of the total cost. 'Of the remaining costs, water users of irrigated land will repay 37 per cent and 5 per cent will be paid by municipalities for domestic water supplies or will be charged to flood control or other non-reimbursable activities.'

The proposed allocation of costs between various purposes on projects at present under construction in India are:—

	Power Per cent.	Irrigation Per cent.	Flood control Per cent.	Navigation Per cent.
Hirakud	61.8	23.3	12.8	2.1
Damodar	51.4	23.6	25.0	0.0
Bhakra and Nangal	61.6	38.4	0.0	0.0
Total	174.6	85.3	37.8	2.1
Average	58.3	28.4	12.6	0.7

These figures bear a fair comparison with the allocations on the American projects.

13. CO-ORDINATION OF RIVER VALLEY PROJECTS

In view of the present economic limitations of the country it is evident that all the projects under consideration by Central and State Governments, cannot be undertaken simultaneously and there must be co-ordination of the activities of government agencies both at the Centre and the States to reduce unproductive public expenditure and expand agricultural and industrial output so that the limited national resources are used strategically to serve the short term economic necessities of the country. There should be an overall plan which will include projects whether under investigation or execution by the Centre or by the States and other agencies. Enough projects should be under investigation and the time table of investigation, planning and execution should be so worked out that by the time machinery and technical personnel now employed on any construction work become free, they could be shifted to new construction. This should be feasible irrespective of the State boundaries in which any particular project may be located. Considerable economies will be possible in the cost of construction if the same construction machinery can be used on several projects one after the other as was done in the case of construction of T.V.A. projects.

It is obvious that best results will be obtained if all objects of a particular multi-purpose project are put under the executive direction of one organization. In the United States, T.V.A. is one outstanding example of this principle. The United States Bureau of Reclamation may be mentioned as another outstanding example of organization dedicated to the planning, design and management of multi-purpose river valley projects for about one half of the area of the United States. The department of the Army, Corps of Engineers, takes care of projects primarily meant for flood control and navigation all over the States.

When a river basin is too big for the executive control of one agency, there should be close co-ordination between the different agencies concerned. An outstanding case of co-ordination between different federal departments and State Governments is the development and control of the Missouri River basin. The Army Corps of Engineers is at work on 5 great multi-purpose reservoirs in the basin and a number of urgent flood control levies and flood walls. The Bureau of Reclamation of the Department of the Interior is constructing a number of important irrigation and power projects. The Department of Agriculture is co-operating with a vital soil conservation programme. The Federal Power Commission is making extensive studies for utilization of potential electric power. Other Federal Departments are co-operating on fish and wild life recreational plans. The people of the valley through their State and local governments are helping in this great undertaking.

The work of these federal departments and the local and State Governments in planning, construction and administration is co-ordinated by the Missouri Basin Inter-Agency Committee. Authorized by resolution of the Federal Inter-Agency Committee in Washington, March 29, 1945, the Missouri Basin Inter-Agency Committee meets monthly rotating among the basin states. It has provided the means through which the Federal Agencies have effectively co-ordinated their activities among themselves and with those of the States. This Committee is composed of one representative of each of the five participating Federal Agencies and five Governors representing the ten Missouri Basin States. Governor members of the Committee are selected by the Missouri River State Committee which is made up of the Governor and two members from each of the ten Missouri Basin States. Inclusion of these governors on the Committee gives representation to the States and assures that the local viewpoint on all problems will be given fullest consideration.

14. ACKNOWLEDGMENTS

Useful notes on multi-purpose projects were prepared by Gurmukh S. Sarkaria, Engineer-trainee from the Library of the U.S. Bureau of Reclamation under the

guidance of the author during his stay at Denver in 1949. These notes have been of great help in the preparation of this paper at a short notice. Acknowledgment is also made to the willing help extended by the Technical Information Section of the U.S. Bureau of Reclamation and the Office of Chief of Engineers, Department of the U.S. Army, in supplying valuable data, which has been freely used in the paper.

15. BIBLIOGRAPHY

1948. Tentative report of Committee on Cost Allocation for Multi-purpose Water projects by a Committee of the American Society of Civil Engineers. (July).
1942. 'Reclamation Hand Book'; *Conservation Bulletin No. 32*; U.S. Department of the Interior, Bureau of Reclamation.
1947. 'Central Valley Project Studies', Problems 8-9 and 10-13. U.S. Department of the Interior, Bureau of Reclamation.
1949. River Valley Projects in India—7 Years' Plan. Central Waterpower, Irrigation and Navigation Commission (August).
- 1949-50. Report of the Fiscal Commission, Volume 1, Government of India Press, New Delhi.
1948. Summary of Plans for Conservation and Development of the Water Resources of the United States—Prepared in the Office, Chief of Engineers, Department of the Army. (June 15).
1949. 'Multi-Purpose Reservoirs': A Symposium. *Proceedings Am. Soc. C.E.* (March) 1949. Bureau of Reclamation Manual, Vol. 3.
1944. 'Sale of Electric Power': A bill proposed before 79th Congress. H.R. 5124. U.S. Government Printing Office, Washington, D.C. (January).
- Sain, K. (1939). 'Economics and Finances of Irrigation Projects'. Punjab Engineering Congress.
- Cisler, W. L. (1950). *Electric World* (May 22); National Power.

DISCUSSION

DR. S. L. HORA stated that Mr. Man Singh in his contribution on Navigation had referred to an advice given by a foreign expert to the effect that in the initial stages of developing river transport attention should be paid to the use of tugs for pulling several country boats at the same time. This was a very sound advice indeed, for it implied the utilization of the existing craft, quicker transport and less fatigue for the operating personnel. Mechanized transport vessels, the expert said, will automatically replace this practice in course of time.

There was a close parallel between the advice given by the river-transport expert and what some of us have been advocating in regard to the development of off-shore fisheries in India. Here also tugs could be used to take out country fishing vessels to new grounds and bring them back to the shore in the evening, thereby saving much time and energy of the fishermen and giving them more time for fishing. The development of mechanized fishing fleet will follow in course of time. But unfortunately this advice was given by Indians and not by foreign experts so it had not received much attention. Any development, Dr. Hora stated, should begin with the fuller use of what we have got already and not with foreign practices which were at present not within India's economy.

With regard to irrigation, Dr. Hora enquired whether the Chinese (Chekiang) practice of partitioning irrigation canals by bamboo screens for fish culture existed in India or not? He was, however, aware of such screens being used in Bengal for catching fish. If it could be possible to introduce Chinese practice in India, large crops of fish could be raised and these canals made multi-purpose in use.

He regretted that Professor N. R. Sen's question with regard to the effect of the river projects on the lower reaches of the river did not receive proper attention yesterday and owing to the absence from the meeting of the persons likely to throw light on the subject it could not be taken up now. In regard to fisheries, he will show that the effect may be very deleterious and therefore advocated that a river-system should be considered as one unit and not developed piecemeal.

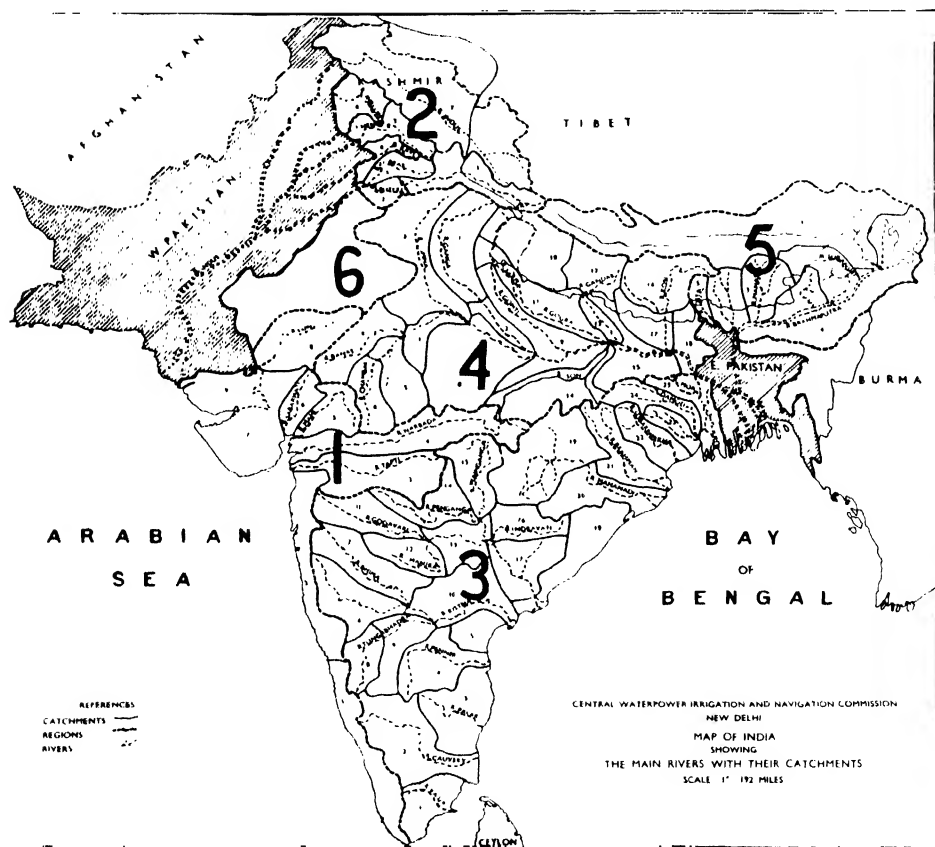


Figure A.

PROBLEMS OF RIVER FORECASTING IN INDIA

By S. K. BANERJI, D.Sc., F.N.I., F.R.M.S., Calcutta.

SUMMARY

The object of river forecasting is to predict the volume of stream-flow or the height of water to be expected in a river channel, lake or reservoir.

Floods are caused by cyclonic storms or depressions which move inland from the Bay of Bengal or the Arabian Sea and the Meteorological Department normally issue warnings for all expected floods. This is comparatively easier than predicting the stages or flows in a river. Yet, an adequate river-forecasting service is a vital necessity in all flood-control plans, as are dams, levees and by-passes. For instance, in the Damodar catchment or the Mahanadi catchment, floods are due to storms from the head of the Bay of Bengal moving westwards or west-north-westwards. While moving, these cause heavy precipitation first in the lower catchment and next in the upper catchment. If no adequate warnings are given, and if the dams are already full, the flood control plan will fail. Then again, without adequate forecasting service, the dams may be left inadequately filled at the end of the monsoon for work during the following dry months.

The forecasting service has to be based on a detailed study of the characteristics of each catchment, which again require provision of data giving quantitative measurements of the condition of the rivers, and of precipitation, temperature, humidity, evaporation, transpiration and wind over the catchments. A study of the basin characteristics must be followed by a full knowledge of the meteorological data affecting the hydrological cycle. This involves a study of rainfall losses (including depression storage), surface run-off, interflow, the ground-water and surface-water hydrographs within and between storms. The rainfall and run-off relationship for each basin must be definitely established.

The development of prediction formulae based on statistical analysis of the past rainfall and river-discharge data involves:

(1) A study of the frequency distribution of precipitation over the catchments for different periods, say '3 days' or '5 days', and also the frequency distribution of river discharges for corresponding periods and their mutual correlations. Provided the statistical data constitute a fairly long series, such analysis enables us to say with an '80 per cent' chance of success that the precipitation, during a certain specified period of '3 days' or '5 days' or any other specified period, will lie between two defined limits and we could similarly say with the same chance of success that the river heights will be between two stated limits.

(2) Working out of definite prediction formulae connecting precipitation over the catchment and the river-heights for 'one-day', '2-days', '3-days' periods, which could be used to predict the expected river height for a given period from a forecast value of precipitation over the catchment during that period or a previous period. A study of correlations between rainfall and discharge data for catchments show generally that the closeness of the association between rainfall and discharge decreases as the 'period' increases. A prediction formula of this kind was given by Mahalanobis to predict the level of the Mahanadi at Naraj one day in advance in the following form:

$$H_n = 1.54 (R) + 0.67 (h) + 23.81$$

where

H_n = predicted height at Naraj on n -th day,

R = total rainfall in inches for a period of 3 consecutive days ending on the $(n-2)$ th day,

h = average height in feet of the river for 3 consecutive days ending on $(n-1)$ th day.

When the value of the total rainfall can be accurately estimated, the error of the height forecast will be between ± 1.2 feet. An error in the estimated rainfall will increase the error of the estimated height.

The problems of river-forecasting in India, taking into consideration all the above aspects, and the development of prediction formulae for definite catchments like the Damodar and the Mahanadi, are discussed in detail in the paper.

So far it has been generally the practice to compute values of meteorological elements for the different political divisions of the country. A map showing the division of the country in terms of catchments of the different rivers has been prepared by the Central Water Power, Irrigation and Navigation Commission. In Appendices I, II, III and IV have been given for the first time the values of (i) mean rainfall, (ii) mean temperature, (iii) the highest and lowest values of rainfall, and (iv) the highest and lowest values of temperature for each of the catchments and for each month and the year. These are the basic data for the hydrological studies of the different catchments.

The object of river forecasting is to predict the volume of stream-flow or the height of water to be expected in a river channel, lake or reservoir. This subject has received a good deal of attention in countries where river projects have reached an advanced stage of development. I give in this article a review of the problems which we have to face in India. In this review use has been made of some of the materials given by Prof. Mahalanobis in his excellent report on the Mahanadi catchment and in some of the publications of the India Meteorological Department.

Heavy rainfall in catchments is associated with the movement of cyclonic storms or depressions from the Bay of Bengal or the Arabian Sea during the pre-monsoon months, April and May, the monsoon months, June to September, and the post-monsoon months, October and November. These are occasional events; the formation and movement of cyclonic storms or depressions can be seen on weather charts, and the meteorological department is able to give a warning for heavy rainfall in most cases at least 48 hours before their occurrence. This is comparatively easier than predicting the stages or flows in a river. Yet, an adequate river-forecasting service is a vital necessity in all flood-control plans, as are dams, levees and by-passes. In catchments like Damodar or Mahanadi, floods are produced by storms, which form at the head of Bay of Bengal and move westwards or west-north-westwards. While moving, these cause heavy precipitation first in the lower catchment and next in the upper catchment. If no adequate warnings are given, and if the dams are already full, the flood control plan will fail. Then again, without adequate forecasting service, the dams may be left inadequately filled at the end of the monsoon for work during the following dry months.

The forecasting service has to be based on a detailed study of the characteristics of each catchment, which again require provision of data giving quantitative measurements of the condition of the rivers, and of precipitation, temperature, humidity, evaporation, transpiration and wind over the catchments. A study of the basin characteristics must be followed by a comprehensive knowledge of the meteorological data affecting the hydrological cycle. This involves a study of rainfall losses (including depression storage), surface run-off, interflow, the ground-water and surface water hydrographs within and between storms. The rainfall and run-off relationship for each basin must be definitely established.

The first essential step is the establishment of a network of meteorological stations recording the elements mentioned above, and the installation of instruments to provide the necessary hydrograph for the river-flow as well as the underground flow. The network of precipitation-gauges has to be so arranged as to give the space-distribution of precipitation with an error not exceeding 10%. The determination of the network involves a statistical examination of the rainfall variance of the existing stations, with particular reference to the topography. With a good network the isohyetal map allows a computation of the space distribution of rainfall over a catchment to be made to a certain degree of accuracy. The accuracy increases with increase in the number of rain-gauge stations. In Damodar catchment, covering an area of 7,200 square miles, a network of 25 rain-gauge stations, gave an error in the determination of space distribution of rainfall of the order of 15 per cent. A network of 60 stations was required to bring down the error to about 10 per cent, and this is the network which has now been established in that catchment.

Storm Analysis.

For storm analysis, Thiessen constructed network by joining the stations with straight lines. If the perpendicular bisectors of these connecting lines be drawn, each station will be enclosed by a boundary midway between it and the adjacent stations. The area covered by each station can be measured and expressed as a percentage of the whole area. A weighted average rainfall for the basin can be obtained by multiplying the record of each station by the percentage of the area

assigned to it and totalling these values. The method is unsatisfactory because it has no physical basis ; it is arbitrary and at the same time inflexible.

It appears that the most accurate computation of average rainfall can be made by means of the isohyetal map. By measuring the area between contours with a planimeter, the average rainfall for the basin can be readily computed. A good amount of rainfall analysis for some of the catchments in India has already been made.

A knowledge of the maximum rainfall that has occurred or is likely to occur over the catchment area as well as the maximum rate at which the run-off water will arrive at the point of outlet from the basin and the duration for which this rate will be maintained, that is the characteristics of 'peak discharges', is essential for the design of flood control reservoirs for the regulation of flood waters.

In Damodar catchment, during the period of 60 years (1891-1950), the five storms, the particulars of which are given below, caused the largest amount of precipitation.

	I Aug. 6-12, 1913	II July 31 -Aug. 7, 1943	III Aug. 8-15, 1935	IV July 29 -Aug. 3, 1917	V June 16-19, 1893
Total storm period rainfall in inches	22.0	21.8	17.9	17.4	15.9
Average rainfall per day of storm period	3.1	2.7	2.2	2.9	3.0
Maximum rainfall in 3 days ..	13.0	10.1	9.4	15.2	13.5
Highest rainfall in a day ..	4.7	6.9	5.1	7.1	8.0

Storms I and II gave the heaviest total rainfall during the storm period. Storm IV gave the highest three-day rainfall of 15 inches. Storm V gave the highest mean rainfall of 8 inches during a period of 24 hours over an area of 7,200 square miles.

The frequency distribution of storm-period rainfall irrespective of the duration of the periods is given below:

Rainfall Range in inches	1.01 to 2.00	2.01 to 3.00	3.01 to 4.00	4.01 to 5.00	5.01 to 6.00	6.01 to 7.00	7.01 to 8.00	8.01 to 9.00	9.01 to 10.00	10.01 to 11.00	11.01 to 12.00	12.01 to 13.00
Frequency ..	161	60	22	15	15	3	3	3	1	1	1	0

These have been plotted in Fig. 1 and a smooth curve drawn through the points. The curve suggests that the chance of storm period rainfall exceeding 13 inches in Damodar catchment is 1 in 200 years.

For the Mahanadi catchment, the absolute maximum observed intensities of average rainfall in inch per day for the whole catchment for 1, 2, 3, 10 consecutive days, based on data of heaviest rainfall during 1891-1928 are given below :

No. of days	1	2	3	4	5	6	7	8	9	10
Maximum intensities of average rainfall in inch per day ..	3.75	2.91	2.24	1.94	1.85	1.72	1.54	1.37	1.24	1.18

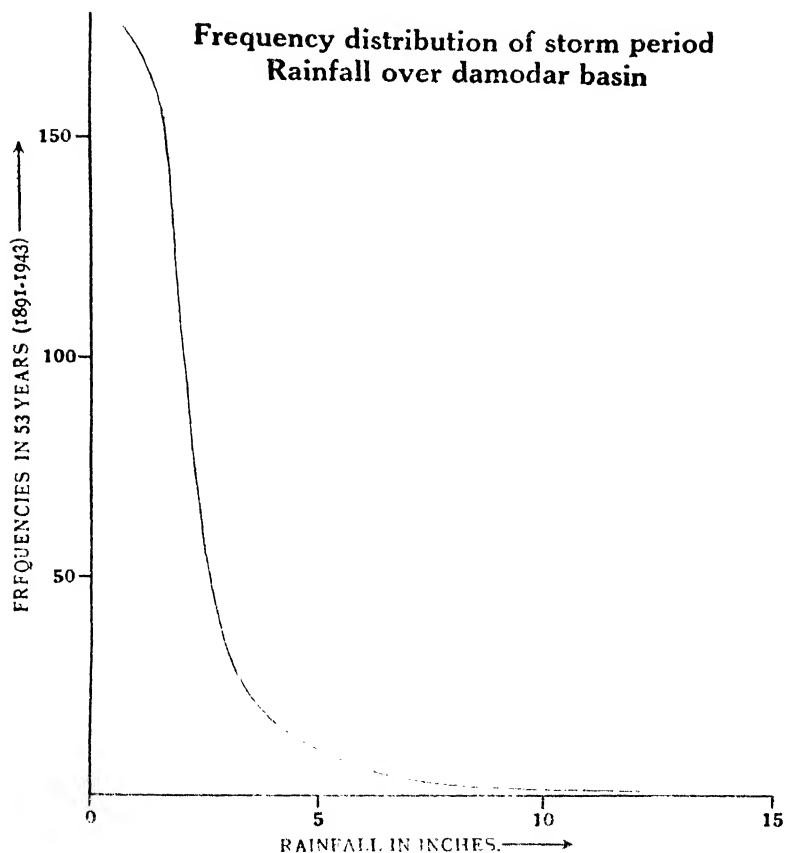


Fig. 1

These figures give an idea of the risk of maximum rainfall in Mahanadi catchment taken as a whole. The accumulated frequency distribution of rainfall intensities for the whole Mahanadi catchment based on 2-5 days' averages, July to Sept. 1891-1928 is shown below :

In excess of inches of rainfall	2 days	3 days	4 days	5 days
1.00	204	117	104	77
1.25	104	53	36	25
1.50	48	21	18	10
1.75	22	10	6	2
2.00	14	8	..	..
2.25	5	1	..	..
2.50	4	..	..	..
2.75	2	..	..	..

The figures in the following table give the probable number of occasions in one monsoon season (July–September) on which different intensities of rainfall in excess of one inch may be expected to occur continuously for periods of ‘2-days’, ‘3-days’, ‘4-days’, etc. over the whole of the Mahanadi catchment.

In excess of inches of rainfall	2 days	3 days	4 days	5 days	6 days	7 days	8 days	9 days	10 days
1.00	10.0	4.7	3.9	3.3	1.6	1.5	1.2	0.9	0.8
1.20	3.9	2.1	1.3	1.3	0.7	0.5	0.1	0.2	..
1.40	2.1	1.3	0.9	0.8	0.1	0.05	..	..	..
1.60	1.3	0.7	0.7	0.4	0.03	..	..	..	..
1.80	0.7	0.5	0.2	0.05	..	..	..	..	..
2.00	0.5	0.4	0.05	..	..	..	..	..	..
2.40	0.3	0.05	..	..	..	..	..	..	..
2.80	0.1	..	..	..	..	..	..	..	..

Thus the probability of 1.2 inches of rainfall occurring continuously for 7 days over the whole of the Mahanadi catchment is once in two monsoon seasons.

It is not only necessary to analyse the space distribution of rainfall but it is also important to analyse the time distribution of rainfall throughout a storm. A ‘mass-curve’ is a plot of accumulated precipitation against time.

The area-depth curve, and the duration-depth curve are useful tools for storm-analysis. The area-depth curve expresses the relation between average rainfall and area for a given storm. The duration-depth curve shows the relation between accumulated average rainfall and storm duration.

The area-depth curves of storm rainfall and time-depth-area curves of maximum likely rainfall have been worked out by Mr. Satkapan for Damodar catchment with particular reference to the storm of 17th to 19th June, 1898, which, as already indicated gave 8 inches of rain over 7,200 square miles. Those curves are shown in Figs. 2 and 3. Similar curves for Mahanadi catchment have been worked out from data given by Mahalanobis and are shown in Fig. 4.

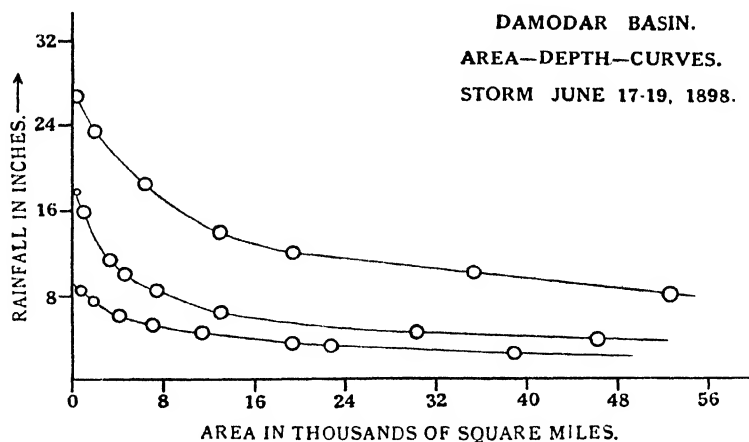


Fig. 2

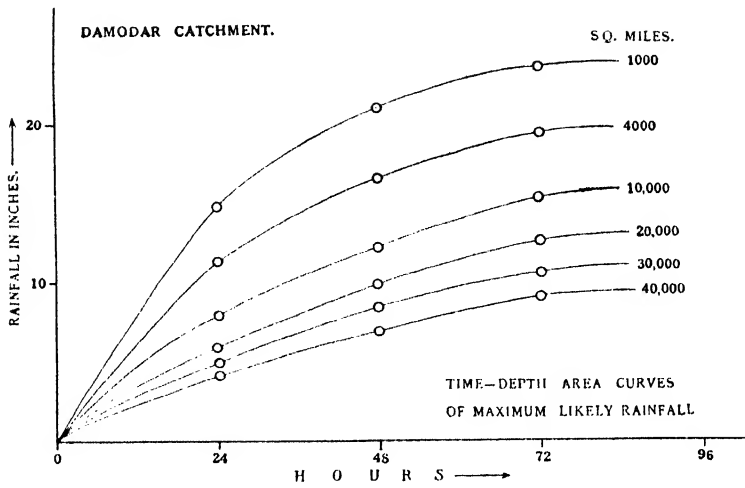


Fig. 3

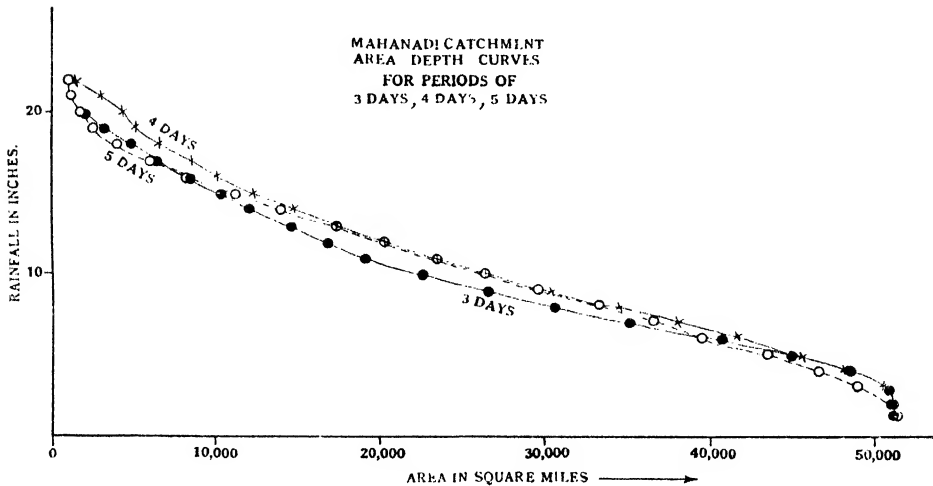


Fig. 4

Ground-water measurements.

Water stored in the ground constitutes an immense reservoir making material contribution to the stream flow. The principal direct measurement of ground water is the elevation of the ground water-table; this is determined by measuring the elevation of water surface in wells.

Basin Characteristics.

It is essential to have adequate knowledge of the basin characteristics. This would comprise :

- Type of soil (rocky, sandy, clay, lava, etc.),
- Land-use (forest, cultivation, range, urban, etc.),

Type of cover (brush, hardwood, evergreen, crops, etc.),
 General Topography (steep slopes, flat slopes, rolling hills),
 Drainage area,
 River mileage,
 Elevation area data, showing drainage areas above and below various elevations.

Rainfall Loss.

The difference between the volume of rainfall and the volume of run-off is the 'loss'. The loss factors cover—

- (a) The *interception loss*, that is, the water held on the leaves, trunks and stems of plants and trees. The water so intercepted is returned to the atmosphere by evaporation.
- (b) The loss due to field moisture, that is, the water retained within the interstices of the soil, the amount depending on the type of soil.
- (c) Infiltration through the soil to the lower layers. A portion of this gravity water goes to the ground water-table whence it travels to the stream channels and springs. Since this underground flow ultimately goes to the stream channels, it does not constitute entirely an item of loss. A portion of the water is held by capillary action in the soil above the water-table, and returned to the atmosphere by transpiration under favourable conditions.
- (d) Loss due to depression storage, and applies to the portion of the precipitation caught in ditches, field, puddles, and other natural or artificial storage basins. Such water remains where it collects until it evaporates into the atmosphere or percolates into the soil.

The amount of water held by foliage, crops and undergrowth will depend on—

- (i) the intensity of rainfall,
- (ii) wind action during and after the storm,
- (iii) thickness and nature of foliage, kind of crop and nature of undergrowth,
- (iv) dry and wet state of plants prior to the commencement of the rain.

The amount held up in this way has been variously estimated to be between 15 to 30 per cent of the rainfall caught in the open.

The absorption losses consist of—

- (i) Evaporation,
- (ii) Transpiration by plants,
- (iii) Absorption by subsoil.

The loss due to evaporation and transpiration by plants will depend on the nature of the terrain, temperature (dry and wet bulb) of the air and wind, and has been estimated to lie between 20 per cent to 40 per cent of the total rainfall.

The loss due to infiltration into subsoil constitutes the principal loss and is considered to depend on—

- (i) Temperature changes.
- (ii) Packing of the soil surface and in-washing of fine material to pores and openings in the soil surface by rain.
- (iii) Previously existing soil moisture content.
- (iv) Cultivation.
- (v) Perforation of the soil and subsoil due to various causes.
- (vi) Shrinking and swelling of surface soils, containing colloidal particles, particularly sun-checking of the soil surface during dry periods.

For any particular catchment this loss can be indirectly estimated.

Run-off.

Run-off is divided into three classes—

Surface run-off is that portion of the run-off which travels over the soil surface to the nearest stream channel. A certain volume of water is required to provide the necessary depth to maintain surface run-off and it is called the surface detention.

It is generally agreed that sub-surface storm run-off occurs but its measurement is difficult. The inter-flow is that portion of the run-off which percolates through the upper soil to the streams without first reaching the permanent water-table. Interflow travels more slowly than does surface run-off.

Ground water flow originates from the water stored beneath the ground water-table. It is usually a continuous source of stream-flow throughout the year. Even where streams go dry during the summer months ground-water flow continues below the channel bottom. The water-level in a stream and the level of the ground water-table at the streams' edges are usually the same (see fig. 5).

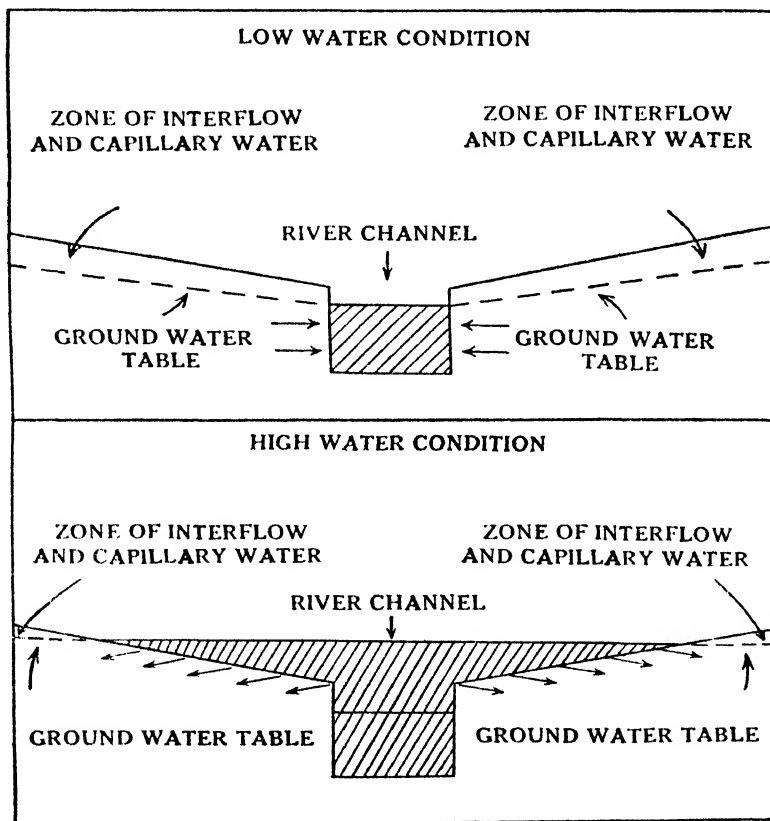


Fig. 5

As rainfall percolates to the ground water-table, the elevation of the water-table is increased, and consequently there is a corresponding increase in discharge to the

stream. When the stream has crested and begins to fall below the level of the water-table, the increase in ground water flow becomes apparent.

A further source of stream flow is precipitation over the channel itself.

Khosla has given an empirical relationship connecting the mean monthly temperature (T_m) expressed in degrees Fahrenheit and monthly evaporation (L_m) in inches in the following form:—

$$L_m = \frac{1}{9.5} (T_m - 32)$$

where T_m is $> 40^\circ\text{F}$.

For $T_m < 40^\circ\text{F}$., he has given the following figures as the evaporation loss:—

T_m	..	..	40°	30°	20°	10°	0°	$^\circ\text{F}$.
L_m	..	..	0.84	0.70	0.60	0.50	0.40	Inches.

The corresponding rainfall (P_m) and run-off (R_m) relationship is expressed in the form, $R_m = P_m - L_m$.

For Mahanadi river at Sambalpur for the year 1932 (catchment area 32,000 square miles), the following figures have been given:—

Month	Precipitation in inches	Temp. in $^\circ\text{F}$.	Calculated loss in inches.	Calculated run-off in inches	Actual surface run-off in inches
July	19.78	80.9	5.15	14.63	6.77
August	11.01	82.3	5.29	5.72	8.46
September	11.25	83.6	5.43	5.82	5.62

The annual precipitation is 52.02 inches, mean temperature 80.1°F ., the calculated run-off is 26.17 inches, while the actual is 25.78 inches.

While as shown by Khosla there is general agreement between the annual value of the calculated run-off and the observed run-off, the variation between the monthly values is considerable. When applied to short periods the relationship is more complicated than the empirical one given by Khosla.

Hydrograph Analysis.

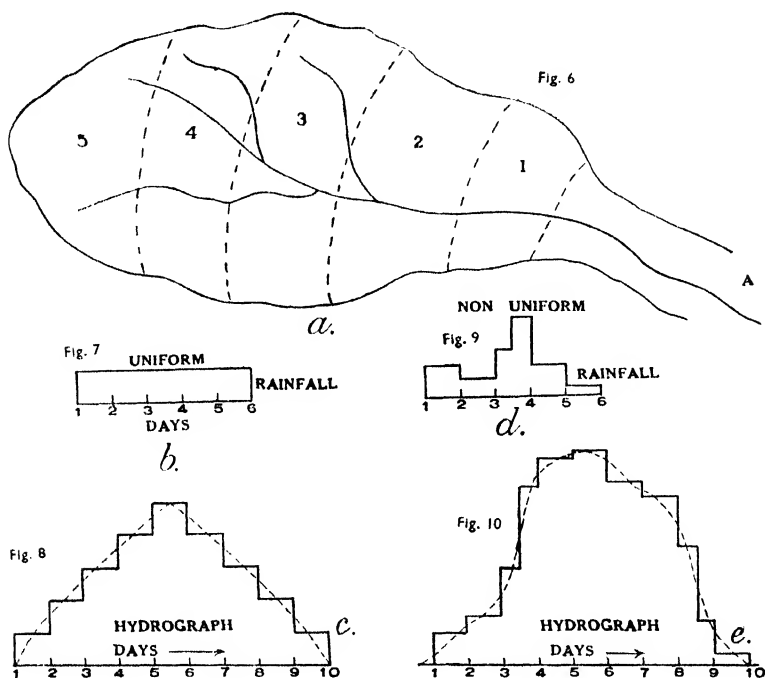
We have discussed so far the disposal of the rain water up to the time it reaches the stream-channels. The behaviour of the 'run-off' after reaching the channels is an important factor in determining the resultant river stages, and must be known fully for the purpose of river-forecasting.

The method of building up the hydrograph at the head-waters by dividing the catchment into a large number of equal strips, from each of which the storm water flows with a uniform velocity, and working out the discharge reaching the head-waters at successive intervals of time is now well recognized.

Essentially the method is as follows:—

Fig. 6 represents a hypothetical drainage basin, which has five sub-areas, marked 1, 2, 3, 4, 5. The numbers indicate the length of time in days required for a small volume of water to travel from the sub-area to the outlet station at A. Fig. 7 represents rainfall at a steady 2 units per hour for four days. The run-off from the sub-area is assumed to have the same pattern as the rainfall. Adding the run-offs from the sub-areas (each delayed by the time necessary to travel from basin to outlet) the outflow at A will appear as shown in fig. 8. Figs. 9 and 10 demonstrate a similar process with a non-uniform rainfall-time pattern. These simple examples show the typical shape of a hydrograph resulting from the variable time required for water

to reach the outlet from the different portions of the basin. When the velocity of the surface run-off over the different strips is known accurately it is possible to make a detailed mathematical analysis of the form of the hydrograph which will result therefrom. A hydrograph is a plot of discharge at a station against the time of occurrence. When such a record is available, it is highly instructive to check up the calculated hydrograph with the actual one.



If the velocity of flow of water were the only factor influencing the shape of the streamflow hydrograph the problems would be comparatively simple. The factor which introduces a complication is the channel storage. Throughout the period of the rise, this factor has the effect of deducting a portion of the flow. Fig. 11 shows a hydrograph for Mahanadi river. Each hydrograph can be divided into three parts. The first part, the ascending limb, starts with the beginning of run-off, and extends to a point near crest, where equilibrium between inflow and outflow begins to be approached. The crest covers a period during which inflow and outflow are in equilibrium. During this period, the aggregate flow from the various sub-areas is at its greatest value. Included in the crest is a small portion of the descending limb of the hydrograph during which surface run-off still occurs. The end of surface run-off is generally believed to occur at the point of inflexion where the descending limb of the hydrograph changes from concave downward to concave upward, the remaining portion of the hydrograph representing only the outflow from the channel storage. Mathematically it can be shown that no such definite point of change need exist under all conditions.

The analysis of the stream-flow hydrograph is a preliminary to the development of forecasting procedures. It serves to determine the volume of run-off resulting from a storm, to separate that run-off into its components of (a) surface run-off,

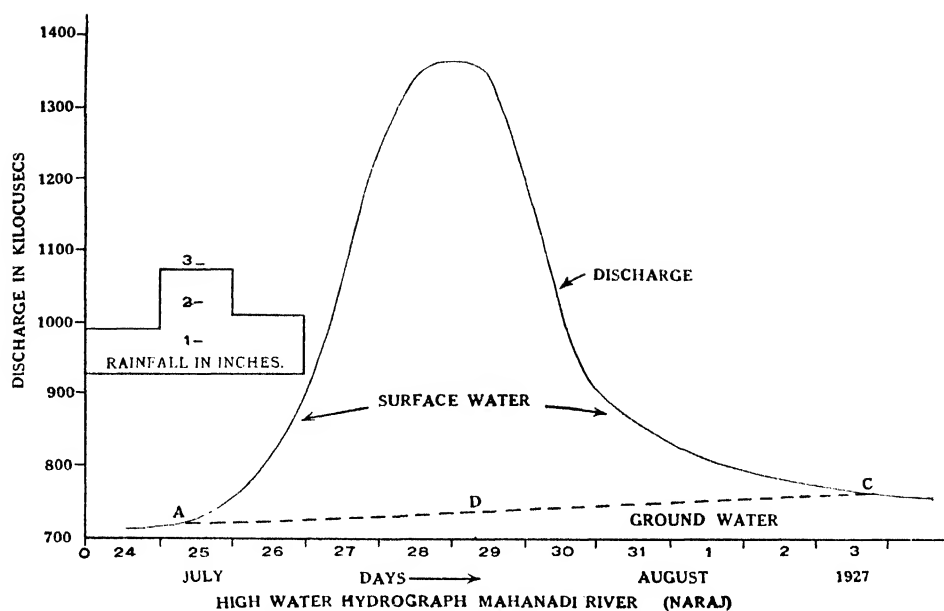


Fig. 11

(b) ground water run-off, and (c) interflow, and to establish certain physical characteristics of the stream under consideration. For Mahanadi catchment divided into five strips, Mahalanobis has given the following figures for the velocity of surface run-off:—

Section	Lag in hours	Equivalent distance from Naraj in miles	Average velocity of flow	
			Miles per hour	Feet per second
M—I ..	43.8	96	2.19	3.21
M—II ..	49.1	200	4.07	5.97
M—III ..	76.0	308	4.05	5.94
M—IV ..	80.8	318	3.95	5.79
M—V ..	100.0	408	4.08	5.98

Excepting in M—I, the mean velocity is of the order of 4 miles per hour. The comparatively low velocities of 2.2 miles per hour in M—I is explained by the fact that the gradient in this section is very small. With these figures, the hydrograph will have very nearly the form given in the illustrative example.

Stream-flow separation.

The simplest procedure for separating the run-off from a given storm is to draw a straight line *AC* from the point of rise to the time at which the surface run-off is believed to have ended. Another method is to extend the recession existing prior to the storm onward to a point under the crest of the current storm and then draw a line to the time of end of surface run-off outflow. (*ADC*, fig. 11.)

Recession Curves.

The separation of stream flow into its three components or between two or more closely spaced storms requires more advanced procedures involving the use of recession curves. The recession curve expresses the normal shape of the falling limb of the hydrograph. The ground water hydrograph should be drawn below the total hydrograph and the surface run-off ordinates computed (total flow *minus* ground water flow) for the determination of surface run-off recession. The recession curves obtained in this manner should agree with all other recession of records for the basin. In other words, at any given flow, the rate of decrease of flow is constant. This conception provides another approach for the development of recession curves. During periods of natural recession, values of flow at any instant may be plotted against the flow at a fixed time later (say 24 hours). The points thus plotted will fall on or near a smooth curve, which expresses the stream-flow recession for the basin. It has been suggested that the recession may be expressed by the equation,

$$Q = Q_0 \cdot K^t,$$

where Q_0 equals the initial flow and Q equals the flow at time t later and K is a recession constant always less than one. If this equation is true the recession will plot as a straight line on semi-logarithmic paper.

River Forecasting Methods.

We may divide forecasting problems into two parts. The first is the prediction of out-flow hydrograph of the headwater basins within the river district. The second is the task of translating these flows from the headwater stations on down-streams. This is extremely difficult work for any basin of more than 1,000 square mile drainage area.

For the purpose of the forecasts we require the rainfall run-off relations under different conditions. The concept of run-off as a remainder after the loss has been subtracted from the rainfall has been already discussed. If a correlation involving the total loss (rainfall *minus* surface run-off) can be developed, the procedure becomes relatively simple. Ground water accretion may be subtracted from the total loss, leaving a net loss consisting mainly of interception, depression storage and soil moisture losses. A few typical rainfall run-off relationships are shown in fig. 12.

The rainfall run-off relation provides the necessary first step for each forecast. The second step is to distribute the run-off with time according to the observed characteristics of each individual basin. This is accomplished by the application of the unit hydrograph principle, developed by Sherman, to each of the head-water areas, as well as to each of the ungauged local areas to the down stream reaches. Once the flows from each sub-area of the basin are predicted, the final job of the forecaster is to combine these flows successively into forecasts for all points on the downstream. For each of our large river basins, these forecasting relations will have to be developed by graphical correlations.

All these calculations involve a forecast of the expected precipitation over the catchment. This is determined by the computation of the expectation from an analysis of the past rainfall data to which is superposed any rainfall anomaly determined from an analysis of weather charts.

An analysis of the past rainfall data enables one to say with an 80 per cent chance of success the limits within which rainfall will lie during any specified period. From the 60 years' rainfall series, 1891-1950, one could work out the frequency distribution of different rainfall amounts, for monthly periods, or fortnightly periods. Taking 80 per cent of the area enclosed by these frequency curves (treated as probability curves) one could specify two limits, within which rainfall could be stated to lie with an 80 per cent chance of success.

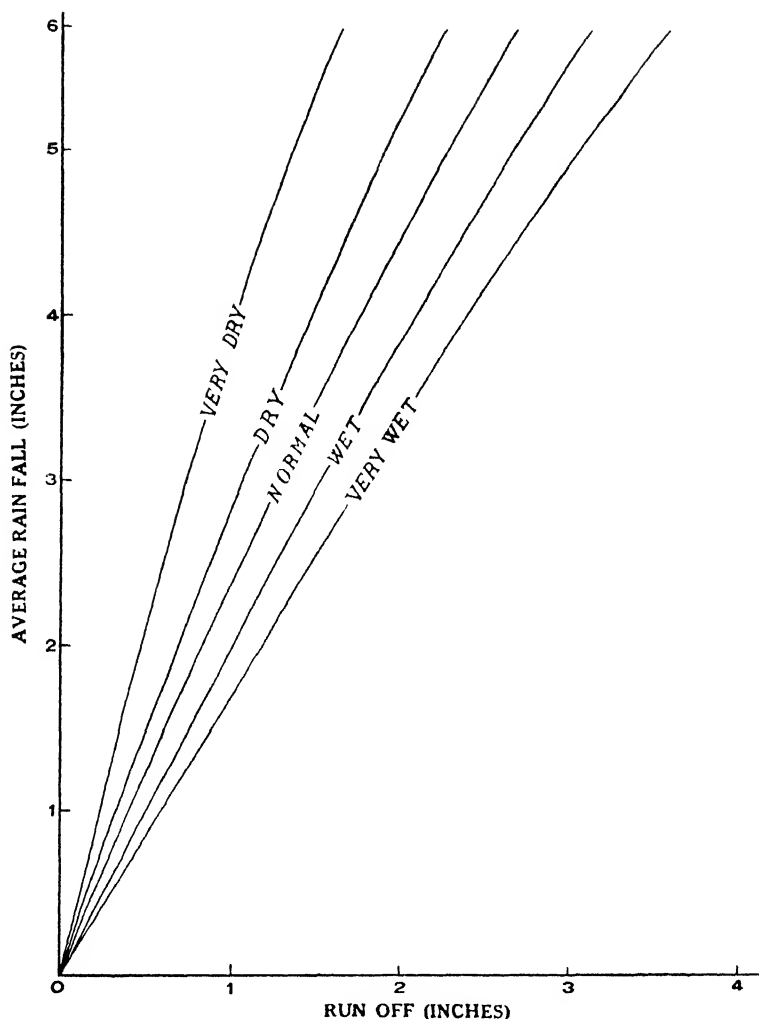


Fig. 12

Figs. 13, 14 give the frequency curves for the Damodar and Mahanadi catchments for rainfall of different intensities for each of the months of July, August and September. From an examination of these curves one could say with an eighty per cent chance of success that in the Damodar catchment, rainfall on any day in July will lie between 0.15 and 1.00, in the month of August between 0.15 and 1.00, and in the month of September between 0.10 and 0.75 inch. Similarly for the Mahanadi catchment, one could say with the same chance of success that rainfall on any day in July will lie between 0.20 and 1.00, on any day in August between 0.20 and 1.25 and on any day in September between 0.20 and 0.75 inch.

Forecasts of this nature, which are based on analysis of past rainfall data constitute standing forecasts. To this must be added any abnormality in the rainfall which can be deduced from an analysis of the current weather charts.

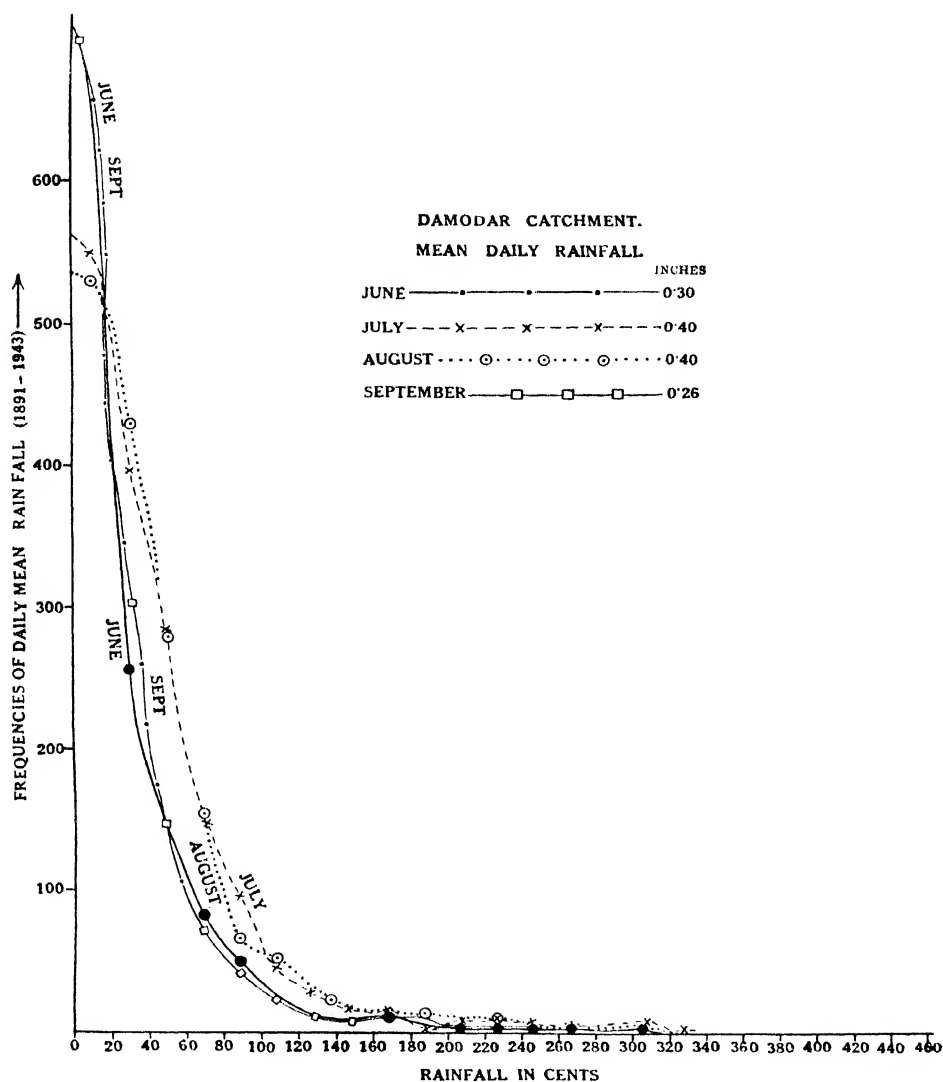
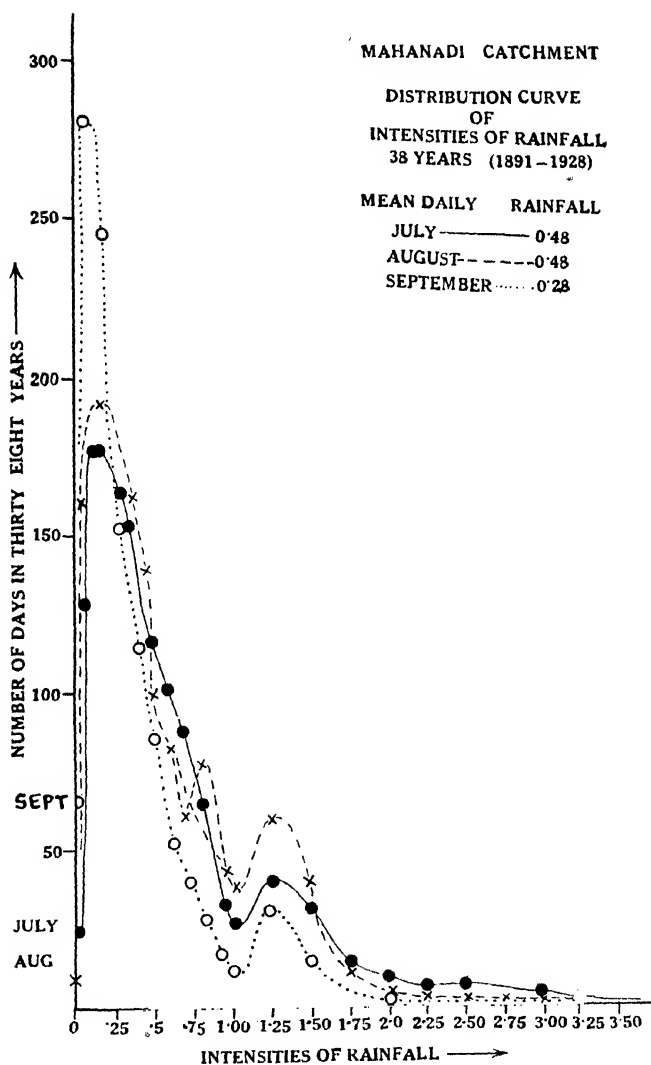


Fig. 13

The correlations between rainfall in the catchment and the river discharges may be utilized to work out prediction formulae.

One such formula to predict the river stage 24 hours ahead has been given by Mahalanobis for the Mahanadi catchment. He observed that in the Mahanadi catchment, it usually requires at least 3 consecutive days of heavy rainfall to produce a flood and that it requires about 2-3 days for the rainfall to make itself felt at Naraj. We therefore take the total rainfall in 3 consecutive days ended two days previously, that is on the $(p-2)$ th day. The previous state of the river has also to be taken



into consideration, and this is done by taking the height of the river at Naraj for 3 consecutive days ending on the day of the forecast, that is, on the $(p-1)$ th day. We have the two factors—

R = total rainfall in inches for a period of 3 consecutive days ended on the $(p-2)$ th day.

G = average height in feet of the river for 3 consecutive days ended on the $(p-1)$ th day.

The following partial correlation coefficients were obtained.

Between N (height at Naraj) and R (rainfall)	..	$0.455 \pm .033$
Between N (height at Naraj) and G (gauge)	..	$0.771 \pm .016$
Between R (rainfall) and G (gauge)	..	$0.041 \pm .040$

These give the following regression equation—

$$N = 1.54(R) + 0.67(G) + 23.81$$

where N is the predicted height at Naraj.

The value of the multiple correlation coefficient is 0.88, which is quite high. This equation will allow individual forecasts to be made within 1.2 feet on an average for floods above 83 feet at Naraj.

From the statistical analysis of past rainfall data and river discharge data, similar prediction formulae can be worked out, and these are of great value in river forecasting.

Rainfall and Temperature Data for the different river catchments of India.

So far it has been the practice to compute the mean values, the highest and the lowest values of the different meteorological elements for the different political divisions of the country.

The natural division of the country is, however, in terms of the catchments of the different rivers. A map of the country showing the catchments of the different rivers has recently been prepared by the Central Water Power Irrigation and Navigation Commission. A copy of this map is given as Frontispiece to this paper (Fig. A).

The country has been divided into six regions, and all catchments in each region has been serially numbered. This is rather an artificial classification. Each catchment is defined by the number of the region followed by its serial number. A more rational system of assigning number to each catchment would be to take the value of the latitude in full degrees just south of the catchment followed by the value of the longitude in full degrees just west of the catchment, and to take the four figures to define the catchment. Thus, for Damodar catchment the number would be 2284. When so expressed the geographical co-ordinates of any station in the catchment can be represented by x, y , where $22+x$ and $84+y$ are the latitude and longitude of the station.

For each of the river catchments I had had the following elements calculated :—

- (1) Mean values of monthly and annual rainfall.
- (2) Mean values of monthly and annual temperature.
- (3) The highest and the lowest values of rainfall for each month and the year.
- (4) The highest and the lowest values of temperature for each month and the year.

These are the basic data which are essential for the hydrological studies of each of the catchments and are given in Appendices I, II, III and IV. The catchment numbers in these tables are those given in the map in fig. A.

The following explanatory notes are offered in respect of these appendices :—

(1) Mean monthly rainfall and the mean annual rainfall for each catchment.

The means are based on the data of all rain gauges—(under the Meteorological Department and Provincial Governments) in each catchment. The latest normals (the 1940) prepared by the Meteorological Department from all available past data have been used.

(2) *Mean monthly and annual temperatures for each catchment.*

Mean temperature $\frac{1}{2}$ (mean maximum temperature + Mean minimum temperature) has been worked out with the data of the relevant observatories, for each catchment (1940 normals). For catchments without any observatory, data of the nearest observatories have been used.

(3) *Highest and lowest monthly and annual temperatures for each of the catchments.*

For each catchment the mean temperature for each month and year has been worked out from the observatories in or near the catchment. The data for 30 years 1911–1940, have generally been used. The highest value for each month and year for these 30 values have been given as the highest value for the catchment. A similar procedure has been followed for picking out the lowest values.

(4) *Highest and the lowest annual rainfall for each catchment.*

The data for the period 1911–1940 (generally) of selected representative stations in each catchment have been used. For each catchment the monthly and annual rainfall based on data of these stations were worked out and the highest and lowest monthly and annual rainfall figures were picked out from these values.

REFERENCES

- Mahalanobis, P. C. (1932). Rain Storms and River Floods in Orissa.
Foster, E. E. (1948). Rainfall and Run-off. (Macmillans.)
Satkopan, V. (1949). A report on the rainfall studies made in connection with the unified development of the Damodar River. *Ind. Met. Dept. Memoirs*, 27.
——— (1950). Time-depth-area curves of Maximum Precipitation for the Damodar Area. *Ind. Jour. of Meteor. and Geophysics*, 1.

APPENDIX I

RAINFALL

(1) *Mean Monthly and Annual Rainfall (in inches) for each catchment*
Catchment Nos. refer to the map given in Fig. A

Region	Catchment No	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1	01	0.66	0.67	1.56	4.23	7.70	23.55	25.99	15.69	5.46	11.29	6.63	1.67	108.11
1	02	0.09	0.06	0.06	0.31	1.11	22.32	37.72	22.84	11.97	4.02	0.91	0.13	101.55
1	03	0.34	0.26	0.23	0.17	0.41	5.71	9.46	6.43	8.15	1.73	0.74	0.30	31.58
1	04	0.41	0.47	0.37	0.26	0.40	6.58	15.23	12.23	7.60	1.77	0.61	0.27	46.20
1	05	0.06	0.06	0.09	0.05	0.31	4.83	12.47	8.90	5.56	0.84	0.26	0.05	33.49
1	06	0.06	0.08	0.06	0.04	0.31	3.82	11.29	7.71	4.35	0.40	0.19	0.04	28.33
1	07	0.09	0.08	0.06	0.03	0.29	3.83	9.01	4.85	3.32	0.69	0.22	0.06	22.50
1	08	0.10	0.15	0.11	0.07	0.35	1.57	4.89	5.71	2.51	0.24	0.09	0.08	15.81
1	09	0.07	0.12	0.06	0.07	0.20	1.59	7.06	3.58	2.12	0.34	0.09	0.06	15.35
2	01	1.6	1.7	1.3	0.9	0.9	3.1	10.0	10.0	4.8	0.5	0.2	0.8	35.8
2	02	1.04	0.98	0.71	0.50	0.48	1.81	5.80	5.26	2.92	0.29	0.09	0.48	20.36
2	03	1.82	1.74	1.35	0.71	0.77	2.83	10.41	10.46	4.06	0.41	0.17	0.87	35.59
2	04	2.10	1.99	1.58	0.82	0.75	2.53	10.17	10.58	3.70	0.45	0.19	0.98	35.85
2	05	2.6	1.9	1.6	1.0	1.0	3.6	11.6	11.6	5.7	0.6	0.3	0.9	41.8
2	06	3.90	4.19	4.67	4.06	2.55	2.39	5.56	5.81	2.72	1.31	0.59	2.02	39.83
2	07	2.93	2.99	4.37	3.55	2.28	1.00	1.37	1.62	1.10	0.94	0.45	1.45	24.05
3	01	1.50	0.84	1.08	2.15	2.04	1.38	1.41	2.20	2.66	0.91	7.19	3.55	32.92
3	02	0.93	0.45	0.61	1.93	3.36	2.67	3.44	4.28	4.72	7.22	6.03	2.72	38.62
3	03	0.94	0.37	0.37	0.96	2.29	2.18	3.09	4.51	0.51	7.46	7.65	2.78	38.10
3	04	0.24	0.17	0.19	0.72	1.76	2.26	2.85	3.60	5.17	4.69	3.03	0.61	25.30
3	05	0.42	0.37	0.27	0.58	1.46	2.24	3.34	3.80	5.08	7.47	5.84	1.05	31.91
3	06	0.09	0.07	0.25	1.14	1.72	5.99	9.29	6.70	5.76	4.11	1.40	0.28	36.80
3	07	0.13	0.12	0.16	0.54	0.92	4.75	6.38	4.37	6.03	2.95	1.24	2.58	27.84
3	08	0.12	0.11	0.33	1.81	3.22	10.28	19.08	10.77	5.15	5.57	2.17	0.49	59.19
3	09	0.08	0.12	0.16	1.04	2.57	2.15	2.24	2.88	4.71	4.29	1.84	0.31	22.40
3	10	0.19	0.40	0.36	0.86	1.38	3.99	5.85	5.46	6.14	3.87	1.83	0.27	30.60
3	11	0.19	0.12	0.14	0.22	0.70	5.63	8.06	5.91	6.61	2.19	0.93	0.23	30.93
3	12	0.11	0.92	0.39	1.09	0.74	6.81	10.63	8.20	7.45	2.47	0.83	0.31	39.97
3	13	0.19	0.85	0.47	0.78	0.70	6.81	13.46	10.06	7.62	2.74	0.77	0.22	44.67
3	14	0.35	0.48	0.41	0.49	0.56	6.80	11.18	8.19	6.83	2.02	0.85	0.32	38.50
3	15	0.34	0.92	0.59	0.63	0.50	8.52	18.45	14.71	8.32	2.41	0.59	0.30	56.27
3	16	0.29	0.72	0.65	1.24	1.61	8.71	18.26	17.40	10.92	3.50	0.81	0.17	63.36
3	17	0.17	0.51	0.55	1.40	2.23	6.45	11.68	10.23	8.24	4.96	1.69	0.23	48.36
3	18	0.28	0.71	0.64	1.08	2.61	5.59	7.11	7.66	7.84	7.34	3.11	0.49	44.46
3	19	0.39	0.99	0.54	0.68	0.75	8.61	15.98	14.70	8.05	2.46	0.61	0.20	53.15
3	20	0.41	0.99	0.80	0.95	2.46	9.38	14.72	14.17	9.43	4.57	1.37	0.19	59.46
3	21	0.63	1.34	1.03	1.16	3.04	9.11	14.86	13.92	8.89	4.42	1.16	0.19	59.83
3	22	0.62	1.43	1.05	1.09	3.15	8.83	13.32	13.00	8.16	3.75	0.73	0.19	55.06
3	23	0.43	1.25	1.20	1.48	4.35	10.28	13.14	12.85	7.92	4.29	0.78	0.13	57.11
3	24	0.47	1.19	0.96	1.03	3.34	8.77	12.02	12.18	7.95	3.55	0.54	0.16	52.17
3	25	0.38	1.02	1.15	1.85	5.41	10.30	11.81	11.51	8.46	3.87	0.68	1.14	56.57
4	01	1.33	1.33	0.79	0.44	0.89	4.70	12.93	12.64	6.79	1.01	0.17	0.57	43.99
4	02	0.60	0.51	0.26	0.18	0.32	3.55	10.86	10.59	6.04	1.40	0.19	0.30	34.80
4	03	0.67	0.62	0.42	0.25	0.45	2.49	7.77	7.65	4.39	0.61	0.12	0.35	25.31
4	04	0.13	0.06	0.07	0.06	0.35	4.63	10.36	9.39	5.64	0.88	0.40	0.10	32.07
4	05	0.30	0.21	0.15	0.13	0.41	4.20	11.90	10.68	5.56	0.73	0.46	0.25	34.96
4	06	0.29	0.26	0.22	0.13	0.39	2.65	7.71	7.73	3.17	0.38	0.13	0.22	23.29
4	07	0.50	0.41	0.21	0.15	0.30	3.52	10.77	10.61	5.57	0.99	0.25	0.27	33.54
4	08	0.54	0.49	0.28	0.19	0.35	4.79	13.94	12.81	6.83	1.17	0.49	0.30	42.19
4	09	0.68	0.71	0.35	0.20	0.56	4.64	12.30	11.05	7.31	1.83	0.25	0.29	40.78
4	10	0.8	0.7	0.4	0.2	0.7	5.5	14.4	13.8	8.6	2.2	0.3	0.3	47.9
4	11	0.76	0.95	0.48	0.30	1.12	6.49	14.49	13.74	8.48	1.97	0.20	0.34	48.79
4	12	0.5	0.8	0.5	0.6	2.2	7.5	13.0	12.6	9.2	2.6	0.4	0.2	50.1
4	13	0.47	0.72	0.40	0.46	1.90	7.63	13.78	12.48	9.45	2.17	0.30	0.17	49.99
4	14	0.80	1.11	0.54	0.32	0.76	5.99	14.13	14.19	7.78	2.07	0.57	0.27	48.54
4	15	0.60	0.86	0.51	0.49	1.86	6.97	12.15	12.10	8.53	2.56	0.42	0.27	47.19
4	16	0.4	0.8	0.9	1.3	3.5	8.8	12.4	12.4	9.2	2.1	0.4	0.2	52.4
4	17	0.37	0.57	0.44	0.79	2.95	8.10	13.13	12.09	9.47	2.44	0.29	0.13	50.43
4	18	0.39	0.68	0.71	1.44	5.24	11.83	14.41	12.92	11.45	3.83	0.38	0.09	63.35
5	01	0.1	0.3	0.7	1.7	2.6	3.9	3.5	3.4	2.5	1.1	0.2	0.1	20.1
5	02	0.6	1.3	2.7	7.0	10.5	15.7	14.4	12.9	10.1	4.6	0.9	0.3	81.0
5	03	0.4	1.1	1.5	3.1	8.0	14.8	15.9	14.9	11.2	5.0	0.9	0.2	77.0
5	04	0.73	1.49	2.82	7.23	11.89	17.35	18.62	16.01	12.28	4.83	0.86	0.36	94.16
5	05	0.5	1.4	2.0	4.2	11.0	20.1	21.7	20.4	15.2	6.9	1.3	0.3	105.0
6	01	0.23	0.28	0.20	0.15	0.29	1.02	3.07	3.50	1.25	0.18	0.05	0.14	10.37

APPENDIX II

TEMPERATURE

Mean Monthly and Annual Temperatures (degrees Fahrenheit) for each catchment
Catchment Nos. refer to the map given in Fig. A

Region.	Catchment No.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1	01	79.9	80.8	82.0	84.3	83.7	79.9	78.7	79.0	79.6	80.2	80.3	80.1	80.8
1	02	76.6	76.4	79.5	82.9	84.9	81.9	79.9	79.5	79.5	81.3	80.8	78.2	80.1
1	03	70.5	73.8	81.7	88.8	92.2	87.5	81.5	80.2	80.8	80.1	74.2	70.0	80.1
1	04	67.3	70.7	78.5	86.5	91.3	87.8	81.3	80.1	80.5	78.8	72.1	67.4	78.5
1	05	68.1	71.6	79.1	87.7	90.9	87.9	81.3	79.8	79.5	79.9	73.7	68.7	79.1
1	06	69.2	72.1	80.0	88.3	92.7	91.5	85.7	83.1	84.1	83.6	77.1	71.1	81.6
1	07	68.1	70.8	78.0	84.0	88.0	88.1	84.2	82.1	82.2	82.1	76.7	70.3	79.5
1	08	63.0	65.5	76.6	86.1	92.3	91.9	86.7	83.5	84.0	81.1	72.5	65.4	79.1
1	09	65.9	70.1	78.5	85.5	88.9	88.5	84.5	82.4	83.3	83.3	75.9	68.1	79.6
2	01	29.0	34.0	45.0	55.0	63.0	67.0	63.0	62.0	68.0	52.0	40.0	31.0	50.0
2	02	55.3	59.3	69.7	81.1	89.9	92.8	88.8	87.1	84.9	77.7	66.2	57.5	75.9
2	03	55.3	59.3	69.7	81.1	89.9	92.8	88.8	87.1	84.9	77.7	66.2	57.5	75.9
2	04	53.4	58.1	66.5	76.4	87.1	90.4	86.1	84.5	83.3	76.3	64.7	56.0	73.3
2	05	56.5	59.9	69.1	79.5	89.1	92.5	87.3	84.7	83.5	77.7	67.1	58.5	75.5
2	06	41.1	44.1	53.1	61.9	70.7	78.3	80.3	78.3	73.3	63.7	53.3	44.4	61.9
2	07	21.0	24.1	35.2	47.3	57.4	65.9	71.9	71.4	63.4	51.4	38.7	28.4	48.0
3	01	77.8	79.9	83.3	86.3	87.3	86.3	85.5	84.9	84.4	82.6	80.3	78.1	79.1
3	02	74.0	77.3	81.5	84.5	84.4	81.2	79.6	79.3	79.3	78.3	75.6	73.5	79.0
3	03	75.4	77.8	81.5	86.4	90.3	89.2	86.9	85.6	84.8	81.8	78.0	75.5	82.8
3	04	76.1	80.4	85.8	90.9	93.3	89.8	86.2	85.4	84.5	82.6	78.1	75.2	84.0
3	05	75.7	79.7	84.8	89.9	92.9	89.6	85.9	85.4	84.3	82.2	77.8	74.9	83.6
3	06	71.8	75.3	80.7	84.8	85.2	79.6	76.1	75.8	76.2	77.3	73.5	70.7	77.3
3	07	71.4	75.2	81.0	87.3	88.8	83.3	79.1	78.3	78.4	78.6	73.7	70.3	78.9
3	08	71.7	75.5	79.7	82.7	82.0	76.6	74.1	74.3	75.0	75.7	73.0	70.7	75.9
3	09	74.4	78.9	84.3	87.6	86.7	82.0	79.3	78.9	78.9	78.6	75.3	72.9	79.8
3	10	74.1	78.2	83.0	88.9	91.8	87.0	82.4	81.6	81.6	80.5	76.0	72.8	81.6
3	11	70.5	74.2	81.4	87.5	90.2	84.3	79.2	78.1	78.3	78.0	72.6	69.0	78.4
3	12	72.3	76.3	83.0	87.1	89.4	82.6	77.5	76.3	76.5	77.3	73.4	70.9	78.6
3	13	72.7	77.1	83.6	89.4	93.5	87.8	81.5	81.4	80.8	79.5	73.9	70.5	81.0
3	14	70.5	74.7	82.8	90.6	95.4	89.3	82.0	81.0	81.8	79.6	73.0	68.7	80.8
3	15	68.0	72.0	80.1	88.0	92.8	87.3	80.1	79.0	80.0	77.7	71.0	66.8	78.6
3	16	66.8	71.7	79.4	85.7	90.0	84.7	78.1	78.1	78.5	76.2	69.7	64.9	77.0
3	17	66.1	71.3	79.3	85.0	88.1	83.1	77.4	77.1	77.6	75.5	69.5	64.3	76.2
3	18	71.6	75.7	80.9	84.8	87.6	86.0	82.7	82.5	82.5	80.6	75.4	70.9	80.1
3	19	66.8	71.1	79.3	87.1	92.3	87.1	79.9	79.6	80.1	77.7	70.3	65.3	78.1
3	20	70.6	75.1	82.1	87.2	90.0	87.1	83.2	83.0	83.4	81.7	75.0	69.5	80.7
3	21	67.0	71.5	79.7	86.6	88.8	86.0	81.6	81.2	81.4	78.7	71.7	65.1	78.4
3	22	65.7	70.1	78.9	86.6	89.4	86.6	82.5	81.9	81.9	78.8	71.1	65.1	78.2
3	23	66.8	71.4	80.0	87.9	89.1	87.1	84.2	83.7	83.9	81.0	73.2	67.0	79.7
3	24	64.8	69.0	78.7	86.3	87.9	86.0	82.9	82.3	82.5	79.4	71.6	65.3	78.1
3	25	65.2	69.6	79.2	86.1	86.3	86.0	83.9	83.6	83.9	81.1	73.3	66.1	78.7
4	01	57.5	61.0	70.8	81.3	88.5	89.3	84.6	82.9	81.6	75.8	66.1	58.7	74.8
4	02	59.7	64.3	75.1	85.7	93.2	93.1	86.6	84.4	83.0	78.8	68.7	60.9	77.8
4	03	56.8	61.5	71.5	82.3	91.1	93.1	88.1	86.0	84.5	77.9	66.8	58.9	76.5
4	04	63.7	67.5	76.8	85.9	92.5	90.0	82.4	80.1	80.7	78.6	70.3	64.4	77.8
4	05	63.2	67.7	76.4	85.7	93.3	90.9	82.9	80.7	81.0	78.3	69.8	66.3	78.0
4	06	61.5	65.1	74.7	84.3	90.9	89.9	83.7	81.1	81.2	78.5	69.7	62.9	77.0
4	07	59.6	63.8	73.1	83.5	91.9	91.7	84.4	82.2	81.7	76.7	67.1	60.7	76.4
4	08	61.6	65.9	76.5	86.6	93.5	92.0	84.3	82.2	82.4	78.4	69.1	62.2	77.9
4	09	60.0	64.4	75.0	85.4	91.4	90.9	85.8	84.3	83.9	78.6	68.7	61.1	77.5
4	10	35.0	39.0	49.0	59.0	64.0	66.0	62.0	61.0	59.0	54.0	43.0	35.0	52.0
4	11	60.1	64.5	74.6	84.5	89.7	88.8	85.3	84.2	83.9	79.2	69.5	61.8	77.2
4	12	36.0	41.0	53.0	63.0	64.0	67.0	64.0	63.0	62.0	57.0	46.0	40.0	54.0
4	13	61.1	64.9	75.2	84.3	87.5	86.9	84.9	84.1	83.8	79.7	70.3	62.6	77.1
4	14	61.6	66.0	76.4	85.2	92.5	90.1	82.9	81.2	81.2	76.6	67.8	61.5	76.8
4	15	64.2	66.3	76.9	86.2	89.1	87.9	84.8	83.9	83.7	79.7	70.3	62.7	78.0
4	16	35.0	37.0	43.0	47.0	52.0	57.0	59.0	58.0	54.0	47.0	41.0	40.0	48.0
4	17	61.7	65.3	74.5	83.1	85.3	85.1	84.3	83.9	83.5	79.6	70.9	63.5	76.7
4	18	62.1	65.9	77.0	82.0	83.5	83.7	83.9	83.7	83.1	79.4	71.3	64.1	76.6
5	01	21.0	26.0	37.0	45.0	48.0	54.0	51.0	51.0	48.0	43.0	32.0	25.0	40.0
5	02	60.7	63.9	69.0	73.4	77.6	80.5	81.3	81.5	80.5	76.9	69.8	62.5	73.2
5	03	63.3	66.6	64.6	79.1	79.4	80.9	82.1	82.4	81.5	78.5	71.7	64.9	75.5
5	04	62.3	65.5	72.3	76.8	79.4	82.1	83.3	83.3	82.2	78.4	70.8	63.8	75.0
5	05	62.2	65.3	72.7	78.8	81.1	82.1	82.9	83.1	82.0	78.5	71.1	64.9	75.5
6	01	59.0	63.4	73.7	84.2	92.3	93.9	89.7	86.8	85.8	80.4	69.8	61.4	78.4

APPENDIX III

Highest and Lowest Monthly and Annual Rainfall (in cents) for each Catchment*
 Catchment Nos. refer to the map given in Fig. A

Region No.	Catchment No.	Highest—1. Lowest—2.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1	01	1	0191	0182	0373	0630	2585	4277	5284	3916	1663	1965	0951	0424	14211
1	01	2	0000	0000	0003	0041	0165	1566	0859	0928	0261	0278	0121	0000	8532
1	02	1	0100	0116	0036	0271	1486	3886	6820	4469	2676	1937	0448	0144	16157
1	02	2	0000	0000	0000	0000	0000	0990	1502	1202	0417	0007	0000	0000	7113
1	03	1	0278	0134	0187	0180	0326	1287	1851	1363	1400	0893	0617	0898	4992
1	03	2	0000	0000	0000	0000	0000	0035	0404	0185	0116	0003	0000	0000	1704
1	04	1	0435	0177	0210	0171	0307	1277	2572	2427	1685	0793	0450	0223	6483
1	04	2	0000	0000	0000	0000	0000	0089	0727	0694	0207	0000	0000	0000	3213
1	05	1	0105	0072	0050	0043	0467	1699	3029	2473	1542	0801	0235	0047	5687
1	05	2	0000	0000	0000	0000	0000	0003	0082	0041	0017	0000	0000	0000	1089
1	06	1	0045	0072	0062	0036	0419	1249	4815	2361	2055	0574	0169	0113	6557
1	06	2	0000	0000	0000	0000	0000	0000	0137	0026	0000	0000	0000	0000	803
1	07	1	0077	0038	0197	0025	0395	1242	1989	1575	1906	0856	0164	0077	4619
1	07	2	0000	0000	0000	0000	0000	0000	0033	0061	0026	0000	0000	0000	918
1	08	1	0156	0120	0144	0085	0361	0622	1883	2335	1645	0584	0083	0105	5845
1	08	2	0000	0000	0000	0000	0000	0005	0069	0060	0006	0000	0000	0000	959
1	09	1	0063	0099	0108	0027	0549	0519	2428	1513	2215	0694	0100	0105	4591
1	09	2	0000	0000	0000	0000	0000	0000	0002	0007	0000	0000	0000	0000	318
2	01	1	0815	0525	0828	0539	0424	0986	1711	2167	1569	0726	0235	0420	6468
2	01	2	0028	0022	0034	0028	0011	0116	0339	0416	0121	0000	0000	0000	3084
2	02	1	0492	0453	0318	0266	0295	0350	1537	1082	1549	0455	0109	0206	4426
2	02	2	0000	0000	0000	0000	0000	0000	0114	0054	0004	0000	0000	0000	1115
2	03	1	0711	0397	0704	0428	0209	0669	2158	1591	1309	0674	0155	0568	6207
2	03	2	0003	0008	0000	0000	0001	0009	0169	0378	0033	0000	0000	0000	1967
2	04	1	0919	0757	0965	0536	0319	0950	2855	2279	1861	0549	0227	0336	8307
2	04	2	0013	0019	0006	0019	0008	0021	0326	0901	0052	0000	0000	0000	2782
2	05	1	1458	0977	1512	0719	0483	0934	2401	1854	1525	0571	0468	0930	8005
2	05	2	0094	0053	0066	0058	0005	0044	0409	0544	0100	0000	0000	0002	4266
2	06	1	1173	0961	1147	0985	0631	0575	0970	1501	0760	0763	0327	1282	5520
2	06	2	0031	0078	0155	0131	0027	0033	0266	0334	0022	0000	0000	0000	3200
2	07	1	0397	0553	0767	0479	0380	0237	0238	0268	0181	0226	0114	0397	2486
2	07	2	0019	0025	0032	0033	0001	0006	0013	0006	0001	0000	0000	0000	565
3	01	1	0674	0402	0385	0457	0477	0249	0519	0597	0462	1652	1935	1641	4367
3	01	2	0000	0000	0002	0021	0043	0003	0007	0034	0029	0219	0251	0040	2432
3	02	1	0436	0204	0211	0507	0883	0502	0716	0716	0769	1719	1407	0858	4685
3	02	2	0000	0000	0000	0065	0124	0122	0122	0133	0074	0201	0114	0021	2654
3	03	1	0713	0363	0365	0731	0902	0354	0917	0826	0867	1977	1951	1497	6344
3	03	2	0000	0000	0000	0000	0032	0066	0130	0169	0190	0040	0078	0000	2545
3	04	1	0285	0230	0199	0387	0600	0433	0846	1199	1140	1175	1200	0534	4010
3	04	2	0000	0000	0000	0001	0012	0110	0049	0067	0101	0005	0008	0000	1506
3	05	1	0421	0225	0395	0655	0413	0567	0863	0687	1013	1701	1857	0475	4395
3	05	2	0000	0000	0000	0000	0000	0039	0053	0047	0107	0015	0000	0000	1612

* For Kosi (4/16) lowest rainfall have been obtained as $\frac{1}{2}$ (twice Gandak value + Tista value) except for annual figure where it is the same value as that of Gandak. For Brahmaputra (5/1), Subansiri (5/2) and Chenab (2/5) the values of lowest rainfall are taken as $\frac{1}{2}$ of the mean rainfall for the corresponding months or year estimated earlier.

APPENDIX III (continued)
Highest and Lowest Monthly and Annual Rainfall (in cents) for each Catchment
Catchment Nos. refer to the map given in Fig. A

Region No.	Catchment No.	Highest—1. Lowest—2.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
3	06	1	0056	0077	0024	0406	0360	0854	3159	1523	1208	0992	0860	0166	7148
3	06	2	0000	0000	0000	0000	0012	0118	0199	0193	0111	0038	0000	0000	1873
3	07	1	0167	0124	0236	0266	0497	0890	1108	0715	1219	0712	0564	0097	4173
3	07	2	0000	0000	0000	0003	0000	0096	0135	0085	0048	0029	0000	0000	1527
3	08	1	0092	0221	0141	0428	0648	1076	1544	1557	0879	1162	0673	0146	6017
3	08	2	0000	0000	0000	0002	0057	0056	0167	0084	0031	0018	0000	0000	2016
3	09	1	0177	0210	0156	0327	0695	0618	0733	0976	1034	1279	0986	0237	4199
3	09	2	0000	0000	0000	0029	0080	0063	0068	0105	0105	0051	0000	0000	1897
3	10	1	0137	0311	0283	0425	0450	0775	1078	0835	1050	1075	0575	0171	4854
3	10	2	0000	0000	0000	0003	0002	0108	0276	0281	0316	0083	0003	0000	2015
3	11	1	0247	0107	0212	0187	0537	1315	1234	0973	1346	0811	0561	0160	4135
3	11	2	0000	0000	0000	0000	0000	0073	0184	0081	0025	0005	0000	0000	1286
3	12	1	0227	0159	0227	0181	0457	1037	1293	1303	1623	0625	0508	0090	5317
3	12	2	0000	0000	0000	0000	0000	0097	0300	0120	0285	0000	0000	0000	2080
3	13	1	0243	0335	0272	0496	0461	1265	1696	1245	1369	0673	0343	0183	5582
3	13	2	0000	0000	0000	0000	0000	0037	0415	0349	0189	0006	0000	0000	1906
3	14	1	0299	0284	0329	0380	0440	1655	2342	1666	1518	1077	0360	0120	5569
3	14	2	0000	0000	0000	0000	0000	0173	0596	0333	0173	0003	0000	0000	2537
3	15	1	0373	0309	0237	0423	0423	1921	2612	2799	1698	1001	0372	0290	7614
3	15	2	0000	0000	0000	0000	0000	0120	0503	0586	0253	0000	0000	0000	3105
3	16	1	0405	0457	0202	0645	0710	1682	2036	2391	1562	0968	0561	0092	7831
3	16	2	0000	0000	0000	0009	0000	0104	0871	0661	0228	0021	0000	0000	3095
3	17	1	0130	0376	0239	0427	0691	1653	2270	1973	1527	1120	0412	0181	7429
3	17	2	0000	0000	0000	0019	0012	0196	0690	0796	0290	0000	0000	0000	3389
3	18	1	0206	0336	0385	0272	1006	1540	1745	3041	1666	1625	1769	0121	10628
3	18	2	0000	0000	0000	0003	0026	0117	0324	0339	0326	0104	0001	0000	2894
3	19	1	0568	0435	0319	0259	0477	1869	2279	2567	1425	0732	0503	0145	7162
3	19	2	0000	0000	0000	0005	0000	0191	0572	0915	0344	0000	0000	0000	3971
3	20	1	0300	0373	0309	0257	0612	2138	2381	2163	1452	1470	0912	0075	8115
3	20	2	0000	0000	0000	0000	0021	0281	0638	0835	0491	0037	0000	0000	4566
3	21	1	0334	0413	0443	0295	0713	1971	3164	2431	1370	1031	0823	0106	7381
3	21	2	0000	0015	0000	0000	0053	0257	0677	0808	0347	0007	0000	0000	4878
3	22	1	0341	0678	0532	0215	0936	1961	2693	2265	1472	1465	0655	0190	7569
3	22	2	0000	0002	0000	0006	0043	0162	0415	0820	0395	0003	0000	0000	4283
3	23	1	0197	0492	0655	0269	0869	2068	2282	2153	1707	1542	0479	0105	7359
3	23	2	0000	0006	0000	0007	0092	0389	0627	0673	0456	0020	0000	0000	4454
3	24	1	0247	0537	0698	0331	0844	2121	1984	1826	1362	1454	0520	0184	7484
3	24	2	0000	0001	0000	0023	0124	0429	0494	0705	0336	0009	0000	0000	4403
3	25	1	0145	0494	0685	0597	1063	2368	1924	2108	1463	1521	0500	0122	8147
3	25	2	0000	0005	0000	0044	0235	0643	0556	0525	0355	0016	0000	0000	4077
4	01	1	0513	0516	0478	0178	0354	1551	2461	2302	2412	0643	0296	0304	7288
4	01	2	0000	0000	0001	0001	0005	0060	0312	0693	0116	0000	0000	0000	2869
4	02	1	0245	0397	0161	0118	0303	1782	2131	1888	1605	0852	0269	0184	5740
4	02	2	0000	0000	0000	0000	0000	0027	0123	0285	0109	0000	0000	0000	2108

APPENDIX III (continued)
Highest and Lowest Monthly and Annual Rainfall (in cents) for each Catchment
 Catchment Nos. refer to the map given in Fig. A

Region No.	Catchment No.	Highest—1. Lowest—2.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
4	03	1	0252	0328	0246	0156	0235	0746	1510	1428	1457	0418	0106	0167	4952
4	03	2	0001	0000	0000	0001	0000	0026	0095	0229	0025	0000	0000	0000	1095
4	04	1	0196	0096	0073	0047	0453	1299	1933	2420	1264	0583	0320	0152	5572
4	04	2	0000	0000	0000	0000	0000	0005	0317	0277	0088	0000	0000	0000	1489
4	05	1	0129	0211	0108	0135	0238	0999	2467	3088	1188	0703	0488	0239	6263
4	05	2	0000	0000	0000	0000	0000	0022	0437	0426	0079	0000	0000	0000	2309
4	06	1	0138	0148	0128	0098	0432	0700	1425	2009	1253	0351	0119	0178	5218
4	06	2	0000	0000	0000	0000	0000	0018	0188	0163	0018	0000	0000	0000	1174
4	07	1	0235	0198	0289	0073	0201	1013	2339	2478	1708	0789	0445	0134	5530
4	07	2	0000	0000	0000	0000	0000	0001	0107	0211	0033	0000	0000	0000	1217
4	08	1	0327	0299	0148	0139	0173	1021	2130	2747	1379	0501	0405	0216	5775
4	08	2	0000	0000	0000	0000	0000	0088	0477	0583	0229	0000	0000	0000	2737
4	09	1	0287	0380	0177	0192	0243	1128	2353	1986	1594	0480	0309	0231	6233
4	09	2	0000	0000	0000	0000	0000	0041	0220	0366	0221	0000	0000	0000	2631
4	10	1	0275	0293	0243	0167	0427	1579	2623	2459	2190	0492	0529	0146	7678
4	10	2	0000	0000	0000	0000	0000	0175	0471	0495	0163	0000	0000	0000	2644
4	11	1	0373	0391	0302	0137	0348	1806	2537	2883	1654	0466	0323	0277	7437
4	11	2	0000	0000	0000	0001	0004	0110	0458	0661	0232	0000	0000	0000	3511
4	12	1	0265	0351	0269	0442	1127	1502	2119	2020	1920	0506	0421	0150	6854
4	12	2	0000	0000	0000	0000	0133	0342	0761	0709	0214	0000	0000	0000	3433
4	13	1	0159	0179	0291	0249	0555	1851	3298	2460	1863	0664	0267	0163	7083
4	13	2	0000	0000	0000	0000	0009	0137	0517	0534	0187	0000	0000	0000	2845
4	14	1	0509	0378	0242	0121	0212	1269	2670	2585	1472	0638	0309	0183	5445
4	14	2	0000	0000	0000	0000	0000	0081	0276	0593	0160	0000	0000	0000	3025
4	15	1	0278	0310	0288	0211	0588	1862	1994	2292	1697	1153	0315	0212	7007
4	15	2	0000	0000	0000	0001	0031	0181	0480	0768	0260	0006	0000	0000	3592
4	16	1	0350	0409	0510	1225	2524	5214	5031	4417	4205	3463	1134	0233	16357
4	16	2	0000	0000	0006	0061	0267	1391	0720	1945	1077	0029	0000	0000	11300
4	17	1	0094	0207	0365	0571	0672	1989	2711	3432	2327	1697	0529	0131	7704
4	17	2	0000	0000	0000	0000	0037	0324	0425	0537	0212	0000	0000	0000	3851
4	18	1	0203	0221	0468	0723	1733	2435	2526	3306	2103	1342	0421	0172	9479
4	18	2	0000	0000	0000	0005	0093	0416	0751	0556	0251	0006	0000	0000	3109
5	01	1	0205	1645	1164	0835	0887	1164	1296	1206	0824	1195	0482	0536	5963
5	01	2	0000	0024	0055	0132	0002	0187	0502	0351	0237	0000	0000	0000	4063
5	02	1	0354	0553	1283	1559	2535	4205	4609	3569	4875	2187	0507	0361	18633
5	02	2	0039	0063	0049	0257	0619	1521	1719	1022	1281	0085	0003	0000	11734
5	03	1	0307	0430	1033	1481	2542	2776	3357	2635	1491	0927	0292	0284	11126
5	03	2	0000	0005	0001	0269	0627	0896	0629	0586	0275	0011	0000	0000	6211
5	04	1	0187	0439	0684	1118	1896	2528	2705	1998	1828	1115	0515	0178	10350
5	04	2	0001	0017	0049	0231	0570	1146	0966	0820	0654	0093	0004	0000	7664
5	05	1	0156	0391	0526	0970	1709	4223	4868	3955	3480	2440	0652	0251	15751
5	05	2	0000	0000	0000	0009	0525	1035	1632	1296	0933	0012	0000	0000	9520
6	01	1	0113	0165	0225	0123	0179	0273	0794	0901	0732	0233	0029	0117	2716
6	01	2	0000	0000	0000	0001	0000	0007	0025	0027	0002	0000	0000	0000	384

APPENDIX IV.

APPENDIX
Highest and Lowest Monthly
Catchment Nos. refer to the

Region.	Catchment.	January.		February.		March.		April.		May.		June.	
		Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	01	81.1	78.2	81.9	79.2	84.0	81.5	85.5	83.1	84.9	80.6	81.7	78.7
1	02	79.4	74.1	78.6	74.7	82.5	77.4	85.1	80.7	87.1	83.7	84.2	80.2
1	03	73.7	67.2	77.1	71.4	85.4	78.2	91.3	84.7	93.9	85.8	92.5	82.2
1	04	70.3	63.4	74.1	67.8	82.0	75.7	89.7	82.6	93.2	83.3	92.7	81.9
1	05	70.9	64.1	74.3	68.2	83.1	76.3	91.3	84.4	93.1	88.3	89.4	82.3
1	06	73.3	64.4	75.7	68.1	86.1	76.0	91.2	84.3	94.9	86.1	94.9	87.7
1	07	72.0	64.4	74.3	67.6	82.1	74.3	86.2	81.3	89.6	84.0	90.5	85.6
1	08	67.9	58.8	71.9	62.8	81.4	71.3	89.8	81.4	94.6	83.3	95.2	87.2
1	09	70.8	60.8	75.4	65.2	81.4	74.7	88.5	82.2	91.3	85.0	93.7	83.2
2	01	46.8	36.5	48.8	37.6	55.5	44.7	63.6	51.4	71.4	57.1	97.2	63.1
2	01	58.9	51.1	63.1	55.1	75.6	64.8	88.3	74.0	96.3	82.4	98.1	88.0
2	02	58.9	51.1	63.1	55.1	75.6	64.8	88.3	74.0	96.3	82.4	98.1	88.0
2	03	58.9	51.1	63.1	55.1	75.6	64.8	88.3	74.0	96.3	82.4	98.1	88.0
2	04	57.4	49.7	59.4	53.4	72.8	63.8	81.3	71.1	92.6	79.9	93.7	85.9
2	05	60.5	53.3	65.2	55.7	76.1	63.6	88.9	72.8	96.6	81.2	97.6	86.1
2	06	44.9	28.0	50.7	31.6	58.3	43.6	67.9	52.1	77.5	62.6	81.6	69.5
2	07	28.5	14.4	30.2	16.7	44.6	30.3	51.5	41.2	63.2	48.9	70.4	59.1
3	01	80.7	77.0	82.5	77.9	85.6	81.5	88.1	84.9	90.2	84.9	88.1	84.5
3	02	76.6	72.4	79.4	74.6	83.1	79.7	86.1	82.6	87.1	81.7	84.1	79.8
3	03	77.9	73.7	79.9	74.8	83.8	79.0	87.2	83.9	92.9	86.9	92.3	86.0
3	04	79.1	73.4	82.3	77.5	87.9	83.7	93.2	87.6	96.3	89.3	92.6	85.8
3	05	78.7	73.1	81.5	76.7	87.1	82.5	92.2	86.8	95.7	89.1	92.7	85.7
3	06	74.5	69.3	77.1	72.0	82.5	76.9	86.5	82.0	86.5	81.3	83.3	77.2
3	07	75.8	69.3	78.1	72.1	83.7	78.3	89.0	84.1	91.4	84.5	86.8	79.1
3	08	73.9	67.8	77.8	70.8	81.9	75.5	83.7	78.4	84.3	75.1	78.0	70.7
3	09	77.7	70.7	81.1	76.1	86.3	81.7	89.2	85.7	88.7	80.0	84.3	79.8
3	10	77.5	70.4	84.4	71.9	86.8	81.8	93.1	84.5	95.9	87.3	92.0	81.1
3	11	74.3	67.7	77.3	71.5	84.5	77.9	91.9	83.1	94.1	83.1	89.3	79.6
3	12	77.7	69.7	80.1	74.0	87.4	81.3	93.0	82.1	93.5	84.3	87.7	77.1
3	13	77.5	69.7	80.3	74.4	86.9	81.7	92.7	83.1	98.5	86.8	94.5	82.1
3	14	74.6	67.0	78.4	71.4	85.7	79.3	93.2	83.3	98.6	86.6	96.0	82.8
3	15	73.5	64.0	74.6	65.7	88.4	75.9	90.9	80.7	96.9	81.6	93.7	81.3
3	16	71.7	64.1	74.8	68.1	82.5	78.0	88.1	80.4	94.4	81.0	89.2	78.3
3	17	72.1	64.9	74.8	68.1	82.3	77.5	88.1	79.7	94.4	81.0	89.2	78.3
3	18	75.4	68.8	77.7	73.9	82.6	79.4	86.8	82.6	90.7	83.8	89.6	82.8
3	19	69.9	63.0	74.1	68.6	83.3	76.4	90.6	82.1	97.4	85.1	94.8	80.1
3	20	73.6	67.6	76.5	72.8	84.1	79.6	89.3	84.9	92.8	86.5	92.0	81.5
3	21	69.1	62.5	73.1	66.3	83.6	75.3	89.3	81.3	94.5	83.3	92.5	80.0
3	22	69.4	61.8	72.2	67.7	81.8	75.7	89.9	81.5	93.5	82.9	92.5	81.2
3	23	71.3	64.2	74.6	69.1	84.7	77.4	91.7	80.1	93.0	84.5	92.5	82.7
3	24	68.0	61.5	71.6	66.8	82.7	74.5	89.8	82.5	91.9	84.0	91.7	79.8
3	25	68.1	62.7	72.6	67.7	83.4	76.7	89.3	81.9	90.3	83.6	88.3	82.1
4	01	60.6	54.6	64.6	59.3	75.7	66.8	87.7	76.1	95.8	83.0	96.0	86.1
4	02	64.6	57.9	67.8	62.9	79.7	71.0	91.0	80.6	98.2	85.3	98.7	88.1
4	03	61.2	53.8	68.3	58.6	78.3	67.5	89.8	77.3	98.0	83.4	98.1	87.3
4	04	68.1	60.0	72.6	64.7	81.4	73.3	89.9	81.6	94.9	82.6	94.2	84.3
4	05	68.1	59.9	73.9	64.4	84.1	69.6	93.1	82.0	99.2	85.9	98.7	84.5
4	06	67.1	57.7	70.7	62.5	79.7	70.5	88.7	79.7	94.1	81.3	94.2	85.3
4	07	64.6	54.8	67.6	59.2	80.7	70.5	92.1	79.3	99.3	84.8	99.5	87.3
4	08	69.1	58.8	69.2	64.0	80.5	72.8	90.8	81.3	97.4	84.4	97.6	82.8
4	09	63.8	57.9	67.4	62.6	79.7	71.1	90.3	80.8	97.4	84.7	96.8	86.5
4	10	47.1	35.2	48.3	40.1	50.5	45.6	63.6	52.7	69.8	66.5	71.8	60.1
4	11	63.7	57.9	66.7	62.3	78.3	70.3	87.3	80.9	94.1	84.7	94.3	84.1
4	12	56.6	47.9	57.1	51.7	65.4	56.1	71.2	65.1	75.7	69.9	77.5	74.3
4	13	64.5	59.7	69.3	62.0	81.3	72.3	89.7	81.8	92.7	84.7	93.2	82.8
4	14	67.3	57.8	68.4	63.6	79.7	72.5	89.7	81.2	96.9	84.3	96.3	84.9
4	15	66.0	60.2	70.2	65.4	82.1	74.6	90.4	83.2	93.5	81.0	94.4	83.1
4	16	45.1	37.4	46.0	41.3	53.5	44.9	58.3	51.2	61.6	56.3	63.4	59.8
4	17	63.5	58.8	67.4	62.1	77.6	70.3	85.9	78.8	88.5	83.1	88.6	82.3
4	18	64.5	59.8	68.5	63.5	77.5	68.9	84.7	77.2	85.8	81.5	85.4	81.3
5	01	28.6	16.9	29.5	23.3	38.3	26.4	44.7	34.1	51.3	40.9	58.7	47.3
5	02	63.2	58.6	66.8	61.9	74.0	66.4	76.8	70.9	81.1	73.9	82.7	78.1
5	03	65.9	60.9	69.1	64.9	78.4	70.5	85.3	74.1	82.0	77.0	83.1	78.4
5	04	64.7	60.3	68.6	63.7	76.2	68.8	80.4	72.7	81.9	77.8	83.5	80.0
5	05	66.2	59.8	68.4	63.9	76.2	69.2	81.6	75.5	83.2	79.3	84.3	80.4
6	01	63.0	55.4	68.5	59.3	79.6	69.0	90.2	79.3	96.8	83.6	97.1	90.1

IV

and Annual Temperature (°F.)

map given in Fig. A

July.		August.		September.		October.		November.		December.		Annual.	
Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
80.5	77.3	79.9	78.0	80.7	77.8	81.2	78.5	81.3	79.2	81.1	77.3	81.2	79.7
85.8	78.7	81.1	76.7	81.1	78.5	84.3	79.0	83.7	78.4	80.3	75.9	81.2	79.5
84.0	80.1	81.3	79.4	82.9	79.1	83.7	77.6	77.5	70.6	72.5	68.0	81.2	78.9
83.4	79.1	81.1	77.9	82.3	78.2	81.6	75.9	74.8	68.2	69.4	64.8	79.4	76.7
82.8	78.7	82.3	77.7	81.5	78.7	83.1	77.7	76.3	71.7	71.4	65.3	80.1	77.7
89.7	82.5	86.3	81.1	89.4	81.2	87.4	79.7	80.3	71.4	74.7	66.9	83.1	79.7
86.5	82.3	84.5	81.1	84.4	80.3	85.3	79.5	79.3	71.2	73.2	67.0	80.6	78.3
90.4	83.0	87.1	80.9	89.7	81.0	84.7	76.7	75.0	66.4	68.3	61.8	81.0	76.4
87.8	82.4	85.3	80.6	85.4	81.1	86.5	79.9	78.8	68.8	70.6	63.8	81.7	77.8
67.1	63.1	64.6	61.7	65.0	59.3	60.4	53.1	53.7	45.5	49.6	39.1	57.1	53.6
94.0	83.5	92.0	84.1	89.8	80.9	81.5	74.0	69.4	52.3	60.2	54.6	78.9	73.7
94.0	83.5	92.0	84.1	89.8	80.9	81.5	74.0	69.4	52.3	60.2	54.6	78.9	73.7
94.0	83.5	92.0	84.1	89.8	80.9	81.5	74.0	69.4	52.3	60.2	54.6	78.9	73.7
88.5	83.7	87.7	82.3	85.8	80.1	78.3	73.2	66.9	60.4	58.5	53.1	78.9	72.0
91.8	83.1	88.9	82.3	86.0	80.6	81.0	71.4	71.3	62.4	61.5	55.2	78.5	73.0
82.7	75.9	80.9	74.9	76.6	68.7	66.7	59.0	54.9	45.6	47.7	36.5	62.8	57.7
74.4	66.6	73.5	68.4	66.9	59.9	55.2	45.0	41.8	28.8	31.4	18.8	49.9	45.7
86.9	83.3	86.3	83.9	86.5	83.4	84.6	81.2	82.4	79.4	79.8	77.6	81.2	82.8
89.4	78.8	80.4	78.8	80.8	78.2	80.1	76.9	77.7	74.6	75.3	71.9	80.1	78.4
89.1	84.5	89.1	84.2	86.3	82.9	84.0	79.8	79.7	76.6	77.3	71.9	83.5	81.7
88.7	84.8	87.1	83.4	86.5	82.4	85.0	80.5	79.8	73.3	77.0	73.0	84.6	82.7
88.5	84.3	86.7	83.3	86.2	82.3	84.1	80.6	81.1	75.9	77.2	72.9	84.3	82.1
77.3	74.7	77.7	70.1	79.3	74.5	78.9	74.0	76.1	70.5	72.7	64.9	78.2	76.1
81.4	77.4	79.3	76.2	81.4	76.7	81.3	75.0	77.3	70.1	72.6	66.9	80.2	77.4
74.7	70.3	76.5	70.5	77.1	71.4	77.4	70.6	74.3	69.5	73.1	67.0	76.6	72.5
81.3	77.5	80.1	76.7	80.6	77.3	80.7	76.0	67.7	73.1	75.7	70.9	80.5	78.3
85.3	81.1	84.2	80.3	83.5	79.9	83.0	79.3	78.7	73.7	75.6	71.0	82.9	80.2
81.4	77.4	79.5	76.1	83.9	76.1	82.4	75.3	76.4	69.3	71.5	66.1	80.6	78.2
79.9	75.3	78.4	75.5	78.5	75.4	81.0	75.9	77.0	70.8	74.4	68.7	80.3	77.4
84.3	80.1	83.1	78.9	83.6	79.2	83.7	77.5	78.1	70.4	73.7	68.2	82.7	79.4
83.9	79.9	82.7	79.4	83.5	79.8	82.8	76.7	76.4	70.2	70.9	66.5	81.5	78.6
88.1	77.6	80.4	77.4	80.8	75.1	79.6	72.2	73.1	66.9	68.7	64.1	79.5	75.1
79.1	75.8	79.4	76.0	80.0	77.1	78.3	75.0	74.5	66.3	68.0	73.3	78.2	74.9
79.1	75.7	78.4	76.0	79.5	77.1	77.9	74.9	74.5	66.3	67.9	63.3	77.7	74.9
83.8	81.5	83.9	81.7	83.9	81.3	82.3	79.4	79.7	73.6	73.1	69.6	80.9	79.2
86.6	78.8	81.3	78.0	81.8	79.2	79.8	76.3	73.7	67.9	67.6	63.6	79.4	76.5
85.4	81.1	84.7	81.6	84.4	82.1	83.1	79.6	78.1	71.7	71.3	61.2	81.4	78.8
83.3	79.1	81.9	79.0	83.4	78.5	81.1	74.6	77.8	67.6	67.4	62.6	79.7	75.5
84.7	80.9	82.8	80.7	83.0	80.3	80.4	76.6	73.9	68.9	66.9	63.1	79.1	76.4
86.1	83.3	84.9	82.7	85.1	82.6	83.2	79.1	76.9	68.1	69.0	62.2	80.7	77.9
84.1	80.6	82.7	80.4	83.7	79.9	80.5	76.7	74.5	68.8	66.7	62.6	78.6	75.7
85.4	83.4	85.0	82.1	85.8	82.7	83.3	79.7	76.9	71.6	67.7	64.0	79.8	77.9
90.5	82.3	87.0	81.5	85.1	79.9	80.0	74.5	69.5	63.3	61.9	56.6	77.3	73.8
93.4	83.3	88.4	82.6	87.6	82.1	82.4	77.6	72.2	65.5	64.8	58.9	79.7	76.2
94.5	84.4	92.4	83.6	88.7	81.8	82.5	75.8	71.3	64.1	63.2	57.3	80.0	75.2
88.1	80.2	83.3	82.4	85.3	78.2	82.4	75.7	76.2	68.0	68.1	62.5	79.4	75.6
92.9	81.4	87.6	79.5	90.1	79.3	85.9	76.2	76.1	67.6	69.1	61.7	82.7	77.0
88.5	80.9	85.2	79.5	86.8	79.3	81.8	75.4	72.5	65.5	66.3	60.7	79.1	74.8
95.6	83.2	91.8	80.9	89.5	79.7	85.0	73.7	74.1	62.0	65.5	57.7	81.4	75.4
89.3	80.9	85.1	80.8	85.9	80.9	88.2	75.9	72.1	65.3	65.5	60.1	79.4	75.7
92.1	83.7	86.7	80.5	86.4	82.1	81.3	74.7	71.7	66.4	63.6	59.4	79.0	75.9
65.8	61.7	64.7	60.4	64.3	58.1	62.6	59.0	55.5	45.4	50.4	38.0	56.9	53.8
88.6	83.1	86.9	82.3	86.6	81.7	81.5	77.3	72.0	67.0	63.6	59.3	78.4	75.9
77.5	72.3	77.3	74.5	76.6	71.9	72.8	64.8	62.6	56.5	54.6	50.3	66.9	64.9
87.5	83.1	86.6	82.7	87.5	82.8	83.2	78.3	73.7	66.0	66.3	60.6	79.4	76.2
88.3	80.8	83.9	80.1	85.5	80.4	81.3	75.1	71.1	65.1	64.3	58.9	78.6	75.6
87.3	83.7	85.2	82.6	86.6	82.6	83.2	78.7	74.5	69.7	66.1	61.3	79.5	77.3
64.5	61.1	64.8	60.9	62.7	55.5	58.6	53.7	52.4	46.0	47.2	41.0	55.8	52.9
86.2	82.3	84.9	82.1	85.3	81.8	82.7	77.1	73.7	68.5	64.8	60.8	77.4	75.4
85.3	81.5	84.7	81.0	87.5	81.7	82.4	77.3	74.2	69.6	66.0	62.3	77.1	75.4
61.5	55.0	59.3	51.7	56.7	45.2	51.9	35.9	37.3	28.1	29.8	16.7	43.8	36.9
83.7	79.0	84.7	79.6	82.3	77.3	81.1	73.8	72.6	67.5	83.8	60.7	74.0	72.2
84.1	80.3	84.0	81.1	83.5	79.7	81.7	76.4	75.5	68.0	67.3	62.6	76.3	74.4
85.4	81.6	85.5	82.1	83.9	80.8	81.9	75.7	74.9	67.9	66.5	61.5	76.1	74.2
85.3	80.3	84.9	80.7	83.7	80.7	81.7	73.4	74.9	69.7	67.1	63.0	77.0	74.8
93.1	86.0	90.1	82.3	90.1	82.3	83.8	77.5	73.0	65.3	64.4	57.0	80.9	76.2

HYDROLOGY

By N. K. BOSE, M.Sc., Ph.D., F.N.I., Director, River Research Institute, West Bengal, Calcutta.

SUMMARY

To interpret the language of the Meteorologist and make it applicable to the specific use of the engineers, a new science has grown up, known as Hydrology. This science is the product of the present century called up by the demands of engineers dealing with multi-purpose river projects. When a river project deals with only one object such as irrigation, power or flood control, the problem is simple and can be dealt with easily, but with the combination of two or three of these objects the complexity of the problem increases and it becomes necessary to know not only the intensity and variation of rainfall throughout the seasons but also their correlation with run-off and river discharge.

The incidence and distribution of rainfall over a catchment have been a subject of intensive study with the meteorologist for the last century, while the observations of discharge of river have been of a very recent growth. The technique of these observations is not yet fully developed and has to be crude in many cases due to the difficulties of the terrain. Hydrology has been mostly concerned in recent years in developing in two directions, increasing and improving the technique of its own observation and secondly, correlating its own data with those collected by the meteorologist. This has not always been easy.

The correlation between the rainfall and the run-off, that is river discharge, is clear enough even to a layman. But for engineers charged with the duty of designing structures across such rivers something more definite than the layman's statement is required. Hence we have such empirical formulæ as those of Dickens, Ryves and Inglis based on Indian records, of Fanning, Murphy, Cooly, Kuichlug, Brunner and Hermann based on the gauging of American rivers. Considering the very nature of the problem such attempts at generalization are likely to be misleading.

In recent years attempts have been made from the theoretical side to correlate rainfall with run-off. Of these the method of 'Unit Hydrograph', first introduced by Sherman in 1932 and developed by others, has been one of the most successful. Zoch has also tried to work out a synthesis of Flood Hydrograph mathematically.

Besides these attempts at correlation between rainfall and run-off, the other line along which the activities of Hydrology have been mostly directed has been in tackling the problem of 'Silt Movement' in rivers. The factors that tend to increase the supply of silt and sand in rivers have been studied carefully and attempts are being made to control these. Methods of land management and erosion have also been improved.

The technique of measuring stream flow and silt charge had been crude in the beginning of the present century and demanded considerable improvement. The collection of basic data for the planning, design and operation of multi-purpose dams, is of great importance and requires to be preserved with great efforts and precision.

CONTENTS

	<i>Page</i>
1. Introduction	421
2. Rainfall and Run-off—Run-off Ratios	422
3. Run-off and River Discharge—Empirical formula—Unit Hydrograph	423
4. Silt—	
A. Soil Erosion: (1) Deforestation	423
(2) Denudation	423
(3) Regime of the lower reaches	423
(4) Delta formation	423
B. Control of Silt: (1) Afforestation	424
(2) Erosion control—Soil conservation	424
(3) Land Management	424
5. Rain Gauge, River Gauge, Discharge and Silt charge—Basic data	424

INTRODUCTION

The previous speaker has discussed the various aspects of rainfall, its incidence, its distribution in area and time and its forecast. He has in fact told us how far the

Science of Meteorology can help the Engineers in designing, constructing and operating a multi-purpose river project. But to interpret the language of the meteorologist and make it applicable to the specific use of the Engineers a new science has grown up known as Hydrology. This Science is the product of the present century called up by the demands of Engineers dealing with multi-purpose river projects. When a river project deals with only one object such as irrigation, power or flood control the problem is simple; but with the combination of 2 or 3 of these objects, the complexity of the problem increased. It became necessary to know not only the run-off discharges, their intensity and variations throughout the seasons but also their correlation with rainfall. The incidence and distribution of rainfall over a catchment has been a subject of intensive study with the Meteorologist for the last half a century while the observations of discharge of rivers have been of very recent growth. The technique of these observations is not yet fully developed and has to be crude in many cases due to the difficulties of the terrain. Hydrology, therefore, has been mostly concerned in recent years in developing in two directions, increasing and improving the technique of its own observation and secondly correlating its own data with those collected by the Meteorologist and gaining thereby from their longer experience and intensive studies. Meteorologists deal with a series of natural phenomenon that are more amenable to scientific treatment while Hydrology is concerned with occurrences that are controlled by natural circumstances whose effects are so varying from place to place and time to time as to be almost unpredictable.

RAINFALL AND RUN-OFF—RUN-OFF RATIOS

To illustrate my point I will cite a few cases of rainfall over the different areas of the Damodar Valley and their effects on the river flow and silt charge during different parts of the year. The complete information has been given in Appendix I. It will be seen from this that the run-off percentage is very small for pre-monsoon precipitation and very considerable for the mid-monsoon precipitation, while for the post-monsoon the run-off percentage is of the medium order. Not only are there seasonal variations from pre-monsoon to mid-monsoon and after monsoon, there are variations from storm to storm. We know if a rain storm is preceded by a few days of light drizzles, the run-off ratio can go up very high, while a dry spell even in mid-monsoon may affect very considerably the run-off ratio for rain storm of the same intensity.

Further the effect of the terrain on the run-off ratios is very pronounced. Even in such a small catchment as that of the Damodar (7,000 square miles) the run-off ratios from the different sub-catchments as those of Usri at Giridih (350 square miles), Konar at Konar Bund (500 square miles), Damodar at Ramgarh (1,250 square miles), Barakar at Barhee (325 square miles) vary very considerably. The difference between the run-off ratios of the river Damodar at Ramgarh where the catchment is yet unoccupied by man and fully wooded, and that of the same river between Ramgarh and Sudamdih an area fully occupied by active coalfields and badly deforested is remarkable. Further the amount of silt charge carried by the river at these two places is also an index of the amount of erosion that is going on in these two catchments. Incidentally these figures of run-off ratios and silt charges should serve as a pointer to us that unless proper precautions are taken the upper valley will very soon degenerate to the same stage as that of the lower valley with the development that is likely to follow the activities of the Damodar Valley Corporation.

In view of the uncertainty and variations met with while determining the values of run-off ratios for different areas and different storms attempts are being made by the Hydrologists of the U.S. Bureau of Reclamation to assess the rates of infiltration and retention in a river valley with the help of a detailed knowledge of the nature of the sub-soil in the area and also with a few infiltration and retention tests in diffe-

rent parts of the valley. These tests coupled with a careful study of the nature of the soil provide them with sufficient information about the base flow and run-off ratios that could be expected in the area.

RUN-OFF AND RIVER DISCHARGE

The correlation between the rainfall and the run-off that is river discharge is clear enough even to a layman. It does not require a scientist to say that if there is rainfall in an area, the river gauges will go up. But for engineers charged with the duty of designing structures across such rivers something more definite than the layman's statement is required. Hence we have such empirical formulae as those of Dickens, Ryves and Inglis based on old Indian records, Fanning, Murphy, Cooley, Kuichling, Brummer and Harman based on the gauging of American streams. All these formulae involve only the area of the catchment raised to different powers and the constant is generally given a range within which it is supposed to vary. These formulae are of the type

$$Q = CA^n + B$$

In some other formulae attempts have been made to incorporate other factors such as Rainfall Intensity and river slope and to vary the constant with the extent and nature of the catchment. Less ambitious but more practical engineers have been content with figures of run-off per square mile of catchments confined to certain specific localities, such as Addams Williams or T. A. Curry's figure for Bengal. Similar figures applicable to very localized areas are also often met with in different parts of the world. They serve the local needs. Attempts are very often made to generalize these local formulae and evolve a universal one. Considering the very nature of the problems such attempts are likely to be misleading and are to be deprecated.

In recent years attempts have also been made from the theoretical side to correlate rainfall with run-off. Of these the method of 'Unit Hydrograph' first introduced by Sherman (1932) and developed by others have been most successful. The basic idea of this method is that every river with its catchment area form a unique system for which if a discharge-hydrograph can be worked out for a certain unit precipitation during a certain unit time then it should be possible to calculate the discharge hydrograph for rainstorms of any magnitude within any units of time. This indeed is a powerful weapon and has already proved its worth in many cases. (See Appendix II.)

Zoch (1934, 1936, 1937) has also tried to work out a synthesis of flood hydrograph mathematically. The determination of a mathematical equation to represent observed stream flow hydrograph has been attempted in two ways. One approach is by fitting a mathematical curve to the observed data and the other by explaining the underlying ideas and observational facts from which the complete solution of the stream flow problem can be obtained in the sense of mathematical physics. Complete solution of the general case has not as yet been obtained. (Appendix III.)

SILT—SOIL EROSION

A river in spate not only brings down enormous volumes of water, it also transports, in very considerable measures, silt and sand from the upper reaches of the valley. These are the immediate outcome of the deforestation and denudation of the upper area accompanied by heavy soil erosion and gully formation. In their turn these silt and sand charges deposit in the river bed as the river enters the flat planes and thereby raise its level. A delta is formed, the capacity of the river is reduced, the flood levels are raised and flooding occurs at a much lower stage.

To control this chain of action, it is certainly preferable and more effective to strike at the root of the cause, deforestation and denudation of the upper reaches than to try to stop flooding by erecting embankments and levees along the lower reach where actually the evil effects manifest themselves. A combination of the two methods is very often necessary depending on the nature and extent of the trouble. This aspect of the problem will be dealt with by other speakers. For the 'Hydrologist' it is necessary to stress on the importance of measuring silt and sand charges carried by the river and also to determine how they are affected by weather, terrain and methods of measurement. For the preservation of the useful life of a reservoir, it is very necessary to deal with this charge of silt and sand brought down by a river. There are various devices to do this. Sluice gates are generally provided at different levels on the body of the dam to deal with different grades of silt and sand charges. A more recent method has been that of the use of the 'Density Current'.

MEASUREMENT OF RIVER DISCHARGE AND SILT CHARGE

The technique of measuring 'Run-off and river discharge' is of very recent origin and is at present far from very accurate. As against river flow measurement river levels had been observed from very olden days. Man in his own safety noted carefully the highest flood levels. Though these gauge readings served very useful purpose in their own way, yet they were not sufficient when rivers had to be controlled or hydraulic structures were to be put up across them. In Italy where rivers had been put to the services of man from very early days, river gauging though in an elementary way had been practised quite extensively. Of late the necessity of accurate river gauging had been felt very acutely in the U.S.A. a land of very fast developing industries. The loss to human life and property that follow in the wake of devastating floods, becoming more and more frequent and intense with the rapid industrialization of the banks of the rivers, has drawn the attention of the Engineers to the necessity and utility of setting up very accurate and elaborate gauging stations all along the river valley. These stations not only read water stages and discharges but also measure silt charge, and temperature. With the possibility of the establishment of various factories and manufacturing concerns on its banks, these stations are now required to assess some chemical characteristics of the river water also. These river gauging stations are now as useful and permanent adjuncts to any river project as the meteorological ones. They should be set up and maintained with the same order of thoroughness and efficiency because the planning, designing and operation of the whole project, nay, its very success depend on the accuracy and sufficiency of the hydrological information supplied by these stations. It is indeed a very short-sighted policy to deal with this fundamental aspect of 'Hydrology' in a stepmotherly way. A well organized Hydrological section should be set up as soon as a River Valley Project is taken up for investigation. Though this section will not bear direct revenue, yet its indirect benefit will exceed many times the direct benefits of any of the operational sections of the Project.

I will now close with the remark that 'Every River is a Law unto itself' and 'Hydrology' which is the Science of River Behaviour will have to study every river individually and intensively before any detailed project on the development of the river and its valley can be drawn up.

REFERENCES

- Sherman, L. K. (1932). Streamflow from rainfall by the Unit Graph Method. *Eng. News Record*, 108, 501-505.
Zoch, R. T. (1934, 1936, 1937). On relation between rainfall and streamflow. *Monthly Weather Review*, 62, 315-322; 64, 105-121; 65, 135-147.

APPENDIX I

Note on the variability study of the Surface Run-off Ratio for different catchments of Damodar

1. An examination of the variability of the surface run-off ratio with the different stages of the monsoon over the Damodar catchment reveal a generally increasing trend in the 'ratio' from the pre-monsoon to the immediate post-monsoon period, to a certain maximum for the ratio. And perhaps, as we recede further from the immediate post-monsoon stage the ratio falls off gradually to reach a minimum in the period just preceding the next monsoon.

2. Probably this maximum state for the run-off ratio is attained when:—

(i) The steady stage for infiltration is reached. At this stage the rate of infiltration is exactly equal to the rate of the internal drainage, that is, the soil is completely saturated with water; and

(ii) there remains no extra capacity for the catchment area to retain water in storage as surface pondage.

3. The trend is apparent from the graph shown for Barakar (Asansol) in Fig. 1.

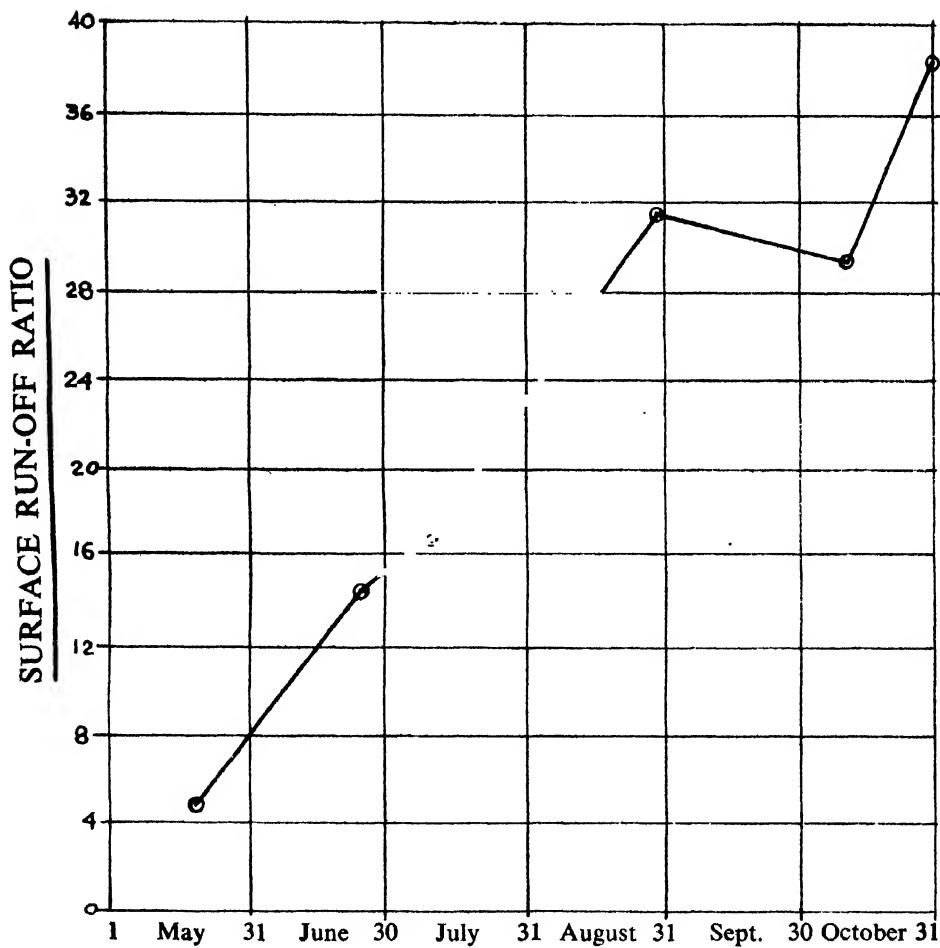
4. Besides being subjected to fluctuations of this seasonal type which is mostly due to soil moisture and surface pondage, the ratio is greatly affected by intensity, rate of rainfall and its distribution over the catchment.

It has not been possible to eliminate completely the effect of these latter factors or to isolate the observations of rainfalls on which the run-off ratios are based to the same degree from the effects of preceding rainfall. These have introduced irregularities besides the chance errors to which any observational data is subject.

5. The silt intensities for pre-monsoon period were not obtainable. Those obtained do not show any definite trend in the stage of the monsoon. But for a single rainfall the silt content seems to be higher during early period of the discharge and gradually diminishes.

Observation stations.	Period.	Rainfall date.	Rainfall in inches.	Total volume of run-off in acre-ft.	Total volume of rainfall in acre-ft.	Run-off ratio per cent.	Average silt intensity (parts per thousand of discharge vol.).
Barhi ..	Pre-monsoon	13-3-47	0.78"	..	..	6	..
Barakar (Asansol) ..		10-5-46	0.71"	..	..	4.7	..
Ramgarh ..		30-5-47	1.02"	..	..	1.3	0.005
Sudamdih ..		..	..	..	..	..	..
Barhi ..	Mid-monsoon	17-8-47	0.92"	..	..	25.4	0.219
Barakar (Asansol) ..		25-6-47	0.52"	..	..	14.4	..
Do. ..		10-7-47	0.77"	..	..	16.8	1.75
Do. ..		30-7-45	0.46"	..	..	31.6	..
Ramgarh ..		11-9-46	0.94"	..	..	33.3	0.89
Sudamdih ..		11-9-46	0.78"	..	..	51.0	0.53
Do. ..		19-7-46	0.37"	..	..	29.4	..
Barhi ..	Post-monsoon	10-10-46	0.8"	..	..	29.2	0.62
Barakar (Asansol) ..		15-10-45	0.43"	..	..	38.1	..
Do. ..		1-10-46	0.64"	..	..	44.0	1.28
Ramgarh ..		8-10-46	0.75"	..	..	49.0	0.70
Do. ..		19-10-46	1.05"	..	..	47.0	0.97
Sudamdih ..		..	..	..	..	..	..

RUN-OFF RATIOS IN BARAKAR CATCHMENT
AT BARAKAR ASANSOL



APPENDIX II

The Unit Hydrograph as a Tool for Analysis of Surface Run-off

The concept of the unit hydrograph was first introduced by Sherman (1932) and later developed by different authors into a useful and efficient tool for the analysis of surface run-off. The unit hydrograph may be defined as 'the hydrograph resulting from the total run-off of a uniform one inch rainfall over the entire catchment occurring in a single unit of time and isolated either ways with respect to time (that is, neither preceded nor followed by any other rainfall whose run-off might overlap the run-off from this rainfall). Merrill Bernard (1935) modified this as the distribution graph giving the distribution of the total run-off in different units of time given in percentages.

The principle of the unit hydrograph is based on the following assumptions:— (i) that the duration of the run-off from any rainfall over one unit of time would be the same irrespective of the magnitude of the rainfall; (ii) that the time distribution of the run-off would be in the same proportion for every rainfall, that is, the proportion of the contributions of the run-off on the successive units of time would remain the same; and (iii) that these contributions to the run-off from rainfall in different units of time would be summable, that is, should be added together to get the resultant run-off.

A direct advantage of the principle of unit graph is that by a judicious application of it, the run-off hydrograph may be predicted from the rainfall records. The only uncertain factor contributing to the inaccuracy in the application of this principle is the run-off ratio or, which is practically complementary to it, the infiltration index whose determination is difficult and inexact.

For the derivation of the unit hydrograph it is necessary to search the rainfall records for an ideal rainfall, viz. isolated rainfall in a single unit of time, sufficiently high and fairly uniform over the catchment. The derivation is shown in the following table.

(1)	(2)	(3)	(4)	(5)	(6)
Unit of time.	Observed discharge in cusecs. (Q)	Base flow in cusecs. (Q')	Net flow in cusecs. ($Q'' = Q - Q'$)	Distribution graph percentage of total run-off. (p)	Ordinates of unit hydro-graph in cusecs. (q)
1	Q_1	Q'_1	Q''_1	P_1	q_1
2	Q_2	Q'_2	Q''_2	P_2	q_2
.
.
n	Q_n	Q'_n	Q''_n	P_n	q_n
			Q''	100	q

$$P_1 = Q''_1 \frac{100}{Q''}; \quad q_1 = \frac{100}{P_1} q$$

The base flow in column (3) is the flow as it would have been in the absence of this rainfall, increased by the contribution due to ground water flow. Column (5) gives the percentage distribution of the net run-off of column (4). The total q of column (6) is obtained by working out the rate of discharge if one inch of rain over

the entire catchment runs off totally in one unit of time (which would be sum of the ordinates of the unit hydrograph), and then distributing this over different units of time according to the percentage distribution of column (5).

For a rainfall giving a total run-off of x inches the run-off hydrograph is obtained by multiplying the unit hydrograph by x , that is, $(xq_1, xq_2, \dots, xq_n)$. For rainfall on different days these run-off hydrographs obtained from them would have to be superimposed to give the total run-off hydrograph.

REFERENCES

- Sherman, L. K. (1932). Stream Flow from Rainfall by the Unit Graph Method. *Eng. News Record*, **108**, 501-505.
 Bernard, M. M. (1935). An approach to determinate Stream Flow. *Trans. A.S.C.E.*, **100**, 347.

APPENDIX III

The Mathematical Synthesis of Flood Hydrograph

Determination of mathematical equations to represent observed stream flow hydrograph can be attempted in two ways. One approach is by fitting a mathematical curve to the observed data and the other by explaining the underlying ideas and observational facts from which the complete solution of the stream flow problem can be obtained in the sense of mathematical physics. Complete solution of the general cases have not yet been obtained but the characteristics of some of the simpler cases are explained here.

Of the various factors like rainfall, run-off, discharge, infiltration and the internal drainage which govern the stream flow, dependable and considerable amount of data are available only for rainfall and discharge. Hence the principles have been deduced entirely from the observations of the discharge.

When discharges following rain are plotted against time on a semi-logarithmic paper the shape of the rising position of the hydrograph is not very apparent but in two cases the falling portion of the hydrograph follows a straight line:—

- (i) Shortly after the peak discharge following a rain which was sufficiently heavy to cause a relatively large run-off or a light rain coming near the end of a long wet spell;
- (ii) After a long dry spell.

In the first case the hydrograph when plotted on an arithmetic paper is asymptotic to a straight line which represents the discharge at the beginning of the rain, in the second case it is asymptotic to the straight line which represents the zero discharge. From this it is found that when the discharge is primarily due to run-off or primarily due to internal drainage, it is a simple exponential function of time for the falling portion of the hydrograph, and so are the corresponding rates of run-off and the internal drainage.

Further analysis of the exponential function of the *rate of run-off* shows that it is proportional to the depth of water remaining with the soil, and this is the basic assumption for solving stream flow problem.

For the simplest stream flow, the drainage area, the rate of rainfall, the duration of rain, the velocity of water and the capacity of the soil are assumed constants for a particular catchment and rain. The distinction between the discharge due to run-off and discharge due to internal drainage is ignored. In such cases the hydrograph for a very small drainage area consist of two parts—a falling part after the rain stops, which is a simple exponential, and a rising part which is complementary to the falling part. For appreciably larger area in this simplest case when the rain lasts longer than the concentration time, the hydrograph generally consists of four

sections. For each one of these four sections a distinct mathematical equation is necessary to express the discharge as function of time. The four sections being:—

- (i) *A concentration curve*:—The concentration curve extends from the beginning of the rain to the concentration time, that is the time when water from the source first reaches the gauge.
- (ii) *A saturation curve*:—This extends from the concentration time till the rain stops. This curve tends to become a straight line as the rate of run-off gradually approaches the rate of rainfall.
- (iii) *A transition curve*:—This extends from the end of the rain until a time equalling the sum of the concentration time *plus* the duration of the rain. During this interval the peak of the hydrograph occurs.
- (iv) *A depletion curve*:—This extends from the end of the transition interval, until an infinite time later (theoretically). This depletion curve is a simple exponential function.

When the duration of the rain is less than the concentration time, the hydrograph again consists of 4 sections with certain modifications. The concentration time extends only up to the end of the rain, instead of saturation curve we get a curve of slow rise extending from the end of the rain to the concentration time, and range of the transition curve changes. If the duration of the rain is exactly equal to the concentration time then the hydrograph consists of but 3 sections, that is, the saturation curve is altogether absent. In two special cases, the hydrographs even for large catchment area have only two sections: (i) when the duration of the rain is practically very short (theoretically zero), (ii) when a storm moves down the stream with a speed exactly equal to the velocity of water in the stream.

The solutions have been obtained for drainage areas with regular shapes, these can easily be extended to the catchments of irregular shape and the varying rates of rainfall may also be considered to a certain extent. Although, this solution for the stream flow problem for the simplest case is only an approximation to the condition found in nature it is broader than any empirical method and indicates the approach to the general solution.

THE RÔLE OF GEOLOGY IN MULTI-PURPOSE PROJECTS¹

By J. B. AUDEN, M.A., Sc.D. (Cantab.), F.N.I., Superintending Geologist, Geological Survey of India, Calcutta.

SUMMARY

The paper outlines the principal ways in which the geologist is concerned with multi-purpose projects. The reconnaissance investigation of river catchments for selection of dam sites is illustrated by work done on the Kosi and Nayar rivers, which are in regions of complicated tectonics. The necessity for detailed investigations by means of tunnels and borings is discussed with particular reference to the Marora dam site on the Nayar river. The investigation of raw materials for construction, such as cement limestones and sources of aggregate, and the examination of reservoir basins for leakage and the flooding of mineral deposits, are then outlined with examples from the Kosi, Ramganga and D.V.C. projects. The paper ends with a discussion of economic potentialities of areas around projects, and the long-term planning which should be adopted before reconnaissance investigations are followed by detailed and costly exploration.

CONTENTS

	<i>Page</i>
1. Introduction	431
2. Regional Geology and Dam Sites	432
3. Silting	434
4. Raw Materials for Construction	434
5. Leakage	435
6. Flooding of Mineral Deposits	435
7. Economic Survey of Project Surroundings	435
8. Long-term Planning	436
9. References	438

1. INTRODUCTION

Engineering Geology may be defined as the application of geological principles to engineering problems. The field is obviously a wide one, because all civil engineering projects are founded on materials which have been formed by geological processes, and are constructed of materials which are either rock or derived from rocks. It is evident therefore that civil engineers should have some knowledge of geology, while all geologists concerned with civil engineering projects should understand something of the structural problems involved. In general, however, the type of geology taught to engineering students is inadequate for a full understanding of the often complicated geological considerations which arise, for example, in dam foundations and the broader aspects of project work, while geologists are certainly not in a position to discuss design, except in so far as it may be possible to indicate that a certain type of design may be unsuited to particular geological conditions. Although there is certainly some overlap of functions, the broad fields of the individual specialists are distinct enough, and it is thought desirable to stress that it is better to distribute specialized functions into those proper to engineers and those proper to geologists, rather than that either worker should attempt entirely to assume the combined functions of both. What the training should do is to enable engineers to appreciate the type of foundation problem involved and advice required, and to call in the right type of specialist. The geologist should, in his turn, learn to anticipate the nature of the data which the engineers require to be expressed in terms capable of translation into engineering practice.

¹ Published with the permission of the Director, Geological Survey of India.

Taken in its widest sense, geology applied to engineering projects includes virtually the whole field of the science. A project comes within a particular geological terrain which, if not already regionally mapped by the Geological Survey, should be studied in sufficient detail to provide a broad picture of the location and structure of the different formations present, the seismic stability, mineral potentialities and erosional characteristics. Particular reaches of the rivers must then be mapped in greater detail in order to locate possible alternative sites for the alignments of dams, the elimination of unsatisfactory sites, and the availability of raw materials with which the dam can be constructed. A decision must then be reached by more detailed study as to the geologically most favourable alignment which is freest from visible structural defects and best situated with regard to construction materials. These materials must be submitted to microscopical and other tests.

Once the superficially most favourable alignment has been selected, detailed exploration follows by means of borings and tunnels, and the information thus obtained has to be plotted and interpreted so as to provide an estimate of excavation required to reach foundation grade, and the zones of weakness which will require special treatment.

In addition the question of leakage from the reservoir basin has to be considered, and an assessment must be made regarding minerals of potential economic value that might be submerged. Finally, the problem of the distribution of minerals of economic value in the area around the Project should be considered in regard to their possible utilization, the absorption of hydro-electric power developed, and improved communications and navigation.

A few examples of these aspects of the work of the geologists are now given from the experience which we have gained in India. It is not proposed to enter into details of foundation exploration, which are of more specialized interest and not suitable in a Symposium of this type.

2. REGIONAL GEOLOGY AND DAM SITES

The Kosi river flows through what was geologically unknown terrain except for a single traverse made 16 years ago through the eastern part of the catchment in connection with a study of the effects of the Bihar-Nepal earthquake. We were fortunate on entry into Nepal in 1946 to be able to identify certain formations from previous experience in the Darjeeling and Kumaon Himalaya. The first two visits, each lasting a day, were sufficient to determine the major rock groups and basic tectonic structure, involving two major overthrusts (Auden and Dutta, 1946), but a much longer time would have been required had routine geological surveys not already covered considerable parts of the Himalaya and rendered comparisons possible (Middlemiss, West, Auden).

In regard to the seismic instability of the region there were available three published Memoirs of the Geological Survey on the Assam (1897), Dubri (1930), and Bihar-Nepal (1934) earthquakes, and also the results of geodetic work carried out by the Survey of India. These studies are sometimes regarded as academic pursuits which should not be fostered by Government Departments whose activities ought to be devoted to the welfare of the people. In actuality, such fundamental knowledge gained from regional geological mapping, geodetic work, and seismic observations, are extremely relevant to the feasibility of projects. It was necessary to emphasize that the Kosi dam site is located only 72 miles from the epicentre of the Bihar-Nepal earthquake of 1934, and must have been close to the epicentral regions of the 1803 and 1833 shocks. The 1934 shock set many landslips in motion within a few miles of the site (Dunn, etc., 1939).

An alignment for the dam was provisionally selected at the third visit made in 1946, after which detailed studies began by means of diamond drill borings and tunnels. As a consequence of these investigations, certain major slate bands were

located, particularly on the left abutment. To avoid these, and to conform more with the hydrodynamic disposal of the spill water, the original alignment was slightly shifted with a small rotation in December 1948. At present 13,600 feet of tunnels and 9,500 feet of borings have been made, and a fair indication has been reached about the depth to foundation grade on the abutments. Excavation will have to extend for an average horizontal distance of 150 feet from ground surface on the left abutment and 200–250 feet on the right abutment above river level. The under-river exploration has not yet been fully carried out, since the possible structural defects present in the pitching and steeply dipping folds of the dam quartzites and slates do not permit of ready correlation by means of vertical holes. It is now proposed to drive horizontal holes from shafts located on the banks. The conclusion is that the site is very likely to be feasible but that considerable excavation and treatment will be necessary.

The basic geological structure of the area around the Marora dam site, Garhwal District, Uttar Pradesh, was known from regional surveys carried out in 1887 and 1936-37 (Middlemiss, Auden). Such traverses, covering thousands of square miles, cannot enter into geological detail at every point, and reconnaissance work done in 1943 at the actual site of the dam in the Nayar gorge showed that there is a complex system of divisional planes intersecting steeply dipping quartzites and slates, which included bedding, cleavage and two sets of joint planes. The combination of these planes created a condition on the right bank of potential liability to slipping. But no major fault was deciphered along the river. Tunnels and borings proved, however, that a major fault zone, concealed on the surface, cuts the left bank under cover of talus and continues downstream and upstream below river gravels. The actual displacement is not considered to have been great, but the fault zone has an average true thickness of 80 feet, and is filled with clay gouge and highly sheeted and crumpled slates. Tunnels on the abutments also proved that there is a system of satellite fault zones parallel to the main river one, filled with clay gouge. Neither at Marora nor at the Kosi dam site are the conditions found to improve materially towards the ends of tunnels 400 feet in length, and the system of faults and shears has been found to be symptomatic of persistent, what may be called, meso-tectonic planes of movement developed by the mega-tectonic overthrusts found in both regions. Furthermore, both at Marora and Kosi, open vertical slump cracks due to gravitational settlement persist for considerable distances into the interior of the mountains sides.

The Marora dam was to have been a concrete structure 640 feet in height, and the alignment was shifted twice in an attempt to avoid the worst defects. A committee convened to study the question of feasibility agreed that a safe concrete dam could be constructed, but that the utmost precautions would be necessary in all phases of excavation and construction so as to obviate falls in the abutments. The treatment of the major fault zone was estimated to cost rupees one crore. The project has now been abandoned on financial grounds, but may be revived within ten to twenty years time. There will then be available the full record of geological results and interpretations based on the tunnels and diamond drill holes. These investigations demonstrate the absolute necessity for detailed exploration, without which at this particular site the major fault zone would not have been discovered until the foundations were laid bare for the actual laying of concrete. Such a major defect, if located only at the very commencement of the construction stage, would have upset all schedules because of the modifications which would have been required in the design of the dam. This pitfall arose during the construction stage of the first St. Gabriel No. 1 dam, where the site had eventually to be abandoned and a new site selected for a totally different design of structure.

This point deserves emphasis because of the attitude of some engineers, fortunately in India very few, that detailed geological investigations are unnecessary and a waste of time. At one dam site in India the drilling programme was not

carried out and, when construction was imminent, it was found that foundation grade had not been reached. The proposed rock surface was well within the weathered zone, with tree roots, highly stained granulitic schist, and clay pockets up to 1,000 cubic feet in volume. The estimates of excavation and volume of masonry were consequently too low, and the construction programme was delayed for several weeks. This setback could have been obviated had the recommended systematic drilling been undertaken to provide a provisional estimate to be made of depth to the foundation grade surface. The preliminary estimate may not necessarily agree with the actual surface proved by excavation, but in general represents a reasonably close approximation. In the particular example in question, emergency drilling done on discovery of the clay pockets by the first excavation indicated a depth to satisfactory rock which agreed closely with that found by fuller excavation.

3. SILTING

The question of silting in the light of the peculiar conditions characteristic of Himalayan catchments has been considered in a separate contribution to this Symposium.

4. RAW MATERIALS FOR CONSTRUCTION

The Kosi dam will be about 750 feet in height from presumed foundation level, and will require from $1\frac{1}{2}$ to 2 million tons of cement, unless pozzolan substitution is made for a part of the cement. This led to what has as yet been a fruitless search for limestones, close to the dam site in eastern Nepal, which might be suitable for the manufacture of low-heat cement. Reconnaissance investigation suggests that there are several areas of limestone on the south side of the Katmandu (Nepal) valley which may prove satisfactory, but these are at present virtually so inaccessible as to vitiate economic exploitation.

The siliceous dolomitic marbles of Bhainse Dobhan, on the main road between Amlekganj and Bhimphedi, were found in general to possess slightly excessive quantities of silica, magnesia and alkalis, but they may prove suitable for beneficiation. Beneficiation methods will certainly be developed as industry necessitates utilizing local materials lacking the ideal composition of cement limestones, and they will eventually become cheaper. At present they are certain to add very materially to the cost of production. Even so, the distance of Bhainse Dobhan by rail to the Kosi dam site would be 380 miles, and 600,000 to 800,000 tons of coal would have to be transported 320 miles by rail from South Bihar to a factory located at Bhainse Dobhan. The nearest existing cement factory to the Kosi dam site is 380 miles distant, on the south side of the Ganga. At present no rail or road bridge exists across the Ganga in Bihar, and the cement or coal would have to be brought across the river by ferry barges. Present indications favour the utilization of one of the existing factories south of the Ganga, but production would have to be stepped up to 1,000–1,500 tons of cement daily to conform to schedules of concrete laying at the dam.

The nature of the source materials for aggregate needs careful consideration, particularly in view of the alkali reaction which has been studied in the U.S.A. as a consequence of the cracking observed in many concretes. Such studies embody petrographical, chemical and other physical tests, which are carried out by collaboration of petrographers, chemists and engineers. It is not at present thought that aggregates containing unstable minerals, which react with alkalis in the cement, are as common in India as in the U.S.A. In the U.S.A. many of the western States are occupied by acid and intermediate volcanics, which locally form the only available source of aggregate, and have considerable quantities of opaline silica. The basic lavas occupying the area in western India known as the Deccan Traps

appear to be free from opaline silica, though chalcedonic silica, particularly in the form of agate, is abundant in some of the flows. Other possibly reactive materials in these lavas are represented by zeolites, in which base exchange reactions are characteristic, together with palagonite and celadonite.

5. LEAKAGE

It is fortunate that the great majority of reservoir basins so far under consideration are watertight, for no reservoirs will exist on any extensive areas of plateau limestones, with solution cavities and a depressed water-table, nor do permeable moraines and outwash sands form part of the reservoir perimeters. The Ramganga Reservoir in Garhwal District, Uttar Pradesh, is situated entirely within the Middle and Upper Siwalik rocks, which consist mainly of alternations of porous sand-rock and clay-shales, together with poorly cemented conglomerates. At the dam site, and forming the southern perimeter, these rocks dip northwards into the reservoir basin. Had only sand-rock been present, this disposition would not have been much impediment to the southward migration of the impounded water into the Gangetic plain, because water could have percolated through the massive sand-rock regardless of the direction of its dip. But the existence of clay-shales, interbedded with sand-rock, all with a northerly dip, should act as an effective barrier against leakage to the south. There will probably be at first considerable apparent water losses as the porous members are primed at their outcrops, but this water will be retained as ground water confined in the sand-rock, and will not escape from the basin.

The dam will be an earth structure, 400 feet in height from cut-off level, with an impervious clay core. The design as at present envisaged involves a northward inclined clay core similar to that of Anderson Ranch, which will abut against at least one of the north-dipping clay-shale members of the Siwaliks, so that there will be a continuous impervious barrier, artificial through the dam and extending naturally into both abutments. It may be stressed that our detailed geological work was greatly facilitated by the regional geological survey which was carried out by C. S. Middlemiss 60 years ago (1890).

6. FLOODING OF MINERAL DEPOSITS

Apart from the canard put up by the Anti-Hirakud Dam Committee about flooding of immense deposits of alluvial diamonds, the only serious case of submersion of valuable mineral deposits with which we have had to deal would arise from the construction of the Aiyar and Bokaro dams. The reservoirs impounded by these dams would result in the submersion of about 9 sq. miles of coal measures in the Ramgarh coalfield and 7 sq. miles in the Bokaro coalfield. The original geological surveys of these coalfields are old, but for their time of great accuracy. New geological surveys have since been in progress (Dutt and Ghosh, 1950), based on 4" = 1 mile maps prepared for air photographs. It is likely that the Bokaro dam project will be abandoned. The Aiyar dam may be reduced in height so as to avoid too much reservoir spread over coal seams near the river in the Dudhmatia and Dhawaiya areas but, if this is done, another dam may then be required upstream to provide the full measure of flood control. Unfortunately, any dams on the main Damodar river upstream of the Aiyar site are likely to cause submergence of coal seams in the area 2½ miles west of Argada in the South Karanpura Coalfield. This matter will shortly receive further attention by the Geological Survey of India.

7. ECONOMIC SURVEY OF PROJECT SURROUNDINGS

Except in the case of the D.V.C. and Hirakud Projects, it has not been possible to undertake a satisfactory survey of minerals likely to be of economic value around

the major projects. The Geological Survey of India has of course data of mineral occurrences throughout India, but these tend to be scattered at too wide intervals, and to lack definitive estimates of probable reserves, to be of immediate value in indicating the mineral potentialities of the surroundings.

In contrast to the relatively diffused mineral occurrences in many parts of India, Bihar and Orissa form an exception in being remarkably well favoured with minerals, some of which have been explored in great detail. Large reserves of coal, iron ore, manganese, chromite, copper, bauxite, mica, limestone, dolomite, and phosphates, have been proved in Bihar (Dunn, 1941) and Orissa (anonymous published reports of the Geological Survey, 1943, 1949). Consequently, the D.V.C. Project is well situated with regard to an already highly industrialized region, with growing potentialities, while power from the Hirakud Project is certain to be absorbed with fair rapidity by the exploitation and treatment of known mineral deposits.

In some cases the existing knowledge of geological structure and resources is sufficient to show that minerals of economic value are not likely to be found in the vicinity. Thus, in the case of the area of the Deccan Traps it can be stated that bauxite is probably the only mineral which can be developed, and in the southern half of Bombay State the bauxite tends to be limited to elevations above 2,500–3,000 feet, thereby reducing the areas for future search. About other regions we are still in the dark. Numerous mineral occurrences have been recorded for example in Nepal, including coal, iron, copper, cobalt and nickel, but available indications are that either these minerals do not occur in economic quantities, or communications are at present so poor that economic exploitation is not yet practicable. Detailed surveys in these almost unknown, and at present topographically and geologically little-mapped, areas may be expected eventually to locate some considerable mineral deposits, but it would be bad economics to use this anticipation of discovery in support for at present entirely hypothetical returns.

8. LONG-TERM PLANNING

During the last five years there has been a bewildering number of major projects under investigation in India, both by the Centre and by the States. It is fully realized that there is urgent need for developing India's water resources to the utmost for the triple purposes of irrigation, hydro-electric power and flood control. Some projects, such as the Kosi, have the primary objective of flood control, and the great cost involved in constructing a dam 750 feet in height, in such an isolated region, is difficult to balance with the many benefits ensuing directly and indirectly from flood control. As geologists we are not concerned with that aspect of the situation, but we are concerned with the local availability of raw materials for construction, with communications, and with the possible utilization of the very large quantities of hydro-electric power which will be generated by some of the projects.

These rivers are difficult of access and the construction of the dams would be an incentive to improve the communications. But new and costly communications may be expensive benefits in the case of as yet undeveloped regions, if their function becomes mainly to serve the construction of the projects rather than to act as arterial routes to open out areas of already proved industrial potentiality.

It is sometimes stated that given new blocks of hydro-electric power, new industries will quickly develop to absorb them. This has proved to be so in North America, where mineral resources are abundant and well scattered throughout the country, and where industrial enterprise is active. It does not follow that such an example will apply so immediately to many regions of India, some of which are known to be ill favoured with minerals and industries, while others are so little explored that their potential resources, if present, will take time to develop.

The Kosi dam will generate 1.8 m. kw., yet it is difficult to see the utilization of so much power in the near future. It is true that the power will be developed

by stages as demand arises, but if the absorption of power is slow, little financial return can be expected on the basis of its sale. Large cities like Bombay and Calcutta are certainly short of power, but before the Kosi dam is built there will be some 350,000 kw. available from Hirakud and 400,000 kw. available from the D.V.C. projects, and the D.V.C. area is much closer to Calcutta than the Kosi. Furthermore, the very recently abandoned Rihand project in the U.P. would have been mainly a power project, developing 230,000 kw., although it would also have provided some measure of flood control over a catchment area of 5,000 square miles, and water for irrigation below the Son anicut. This project was more advantageously located than the Kosi to the industrial centre of Kanpur and the cities of Allahabad and Banaras, but has notwithstanding been dropped, presumably because of the redundancy of power in that part of northern India.

It has taken nearly 30 years for 500,000 kw. of hydro-electric power to be absorbed in India. While demand will unquestionably be greatly accelerated in the future, it can scarcely be supposed that the 2.5 m. kw., about to be generated by the Kosi, D.V.C. and Hirakud Projects, will all be rapidly utilized in north-eastern India.

The Bhakra-Nangal Project, shortly to prove of immense value for irrigation of hitherto poorly watered areas, even as far distant as northern Rajasthan, will also eventually generate 390,000 kw. Some of this power is already required by Delhi, Simla, and the Punjab cities, but the utilization of the remainder is still a matter of considerable concern to the engineers, particularly in view of competition from the Yamuna Hydro-electric Project, only 100 miles distant from Nangal, from which it is expected to develop over 50,000 kw. Extensive mineral deposits are not known to occur in the immediate area of either project, but in this case regional surveys have been of value in indicating the possible development of electro-metalurgical and electro-chemical industries.

- (a) The bauxite of Riasi, near Jammu, is 160 air miles distant from Bhakra.
- (b) The magnesite of the Almora area is 260 air miles distant. When worked, however, the necessary power would be obtained from the neighbouring Sarda Project rather than from Bhakra-Nangal or Yamuna.
- (c) The copper of Almora and Khetri, after local conversion into matte, could be electrically smelted at some central station in the plains by Bhakra-Nangal power.
- (d) Sulphuric acid could be made by electrolysis of sodium sulphate common in the Rajasthan salt lakes (Watson, 1923; Auden and Gupta, 1942).

The river potentialities of India deserve extensive reconnaissance by engineers and geologists, and it is strongly suggested that such work should be undertaken as part of a comprehensive long-term survey of water resources, in which all feasible dam sites should be examined and recorded, together with discharge data. Only then will it be possible to draw up a sound plan on an all-India basis, based on the relative proximities of particular sites to construction materials, and to the mineral and other resources in each region potentially capable of industrial development. What is questioned is the wisdom of simultaneously undertaking so many mutually competing projects, far beyond the reconnaissance stage to one of active and costly exploration, without any adequate appreciation of the distribution of natural resources, or any planned scheme for the utilization of the large quantities of power developed. It is understood, for example, that the cost of investigation of the now abandoned Rihand Project amounts to Rs. 1½ crores (£1,100,000), and other projects involving very large sums of money have suffered a similar fate, partly because they have been found, long after promulgation, to conflict with each other.

Only a short while ago, 13 major projects which were under investigation would have required approximately 10.4 million tons of cement, while the road programme, even if drastically reduced from the scale envisaged four years ago, may require

about 8 million tons of cement. The present annual installed capacity of cement factories within the Indian Republic is 2.78 million tons. It is evident that all the dams and road projects would not be undertaken simultaneously, but if construction were staggered over a period of 10 years, some 1.8 million tons of cement would be needed annually for dams and roads in addition to present requirements. It is not possible, however, to spread the cement production required for dams uniformly throughout an arbitrary period such as ten years, because during actual construction the output of factories close to the larger dams would have to be of the order of 1,000 to 1,500 tons of cement daily. This is a large figure, but modest when compared with the rate of placement of concrete at the Grand Coulee dam, which reached a maximum of 15,800 cubic yards in one day, requiring 2,700 tons of cement. The record daily cement production from a single plant in India was 730 tons in 1946.

It would thus appear that there would have to be a larger installed capacity in certain factories, to satisfy concrete-laying schedules of the major dams lasting 3-4 years, than might afterwards be required for the more general civil requirements. The highways will, it is true, require large quantities of cement; but their development is contingent on available finances, now considerably overstrained as a consequence of other schemes.

As discussed in a separate article on Cement, the present tendency abroad is to substitute some of the cement with pozzolans, but research in this direction has scarcely begun in India, and it is unlikely that such pozzolan substitutions will be put into major concrete structures in this country until much more is known about the properties of pozzolan concrete made from local materials.

It does not appear, indeed, that the implications of the simultaneous investigation, and apparently intended almost simultaneous construction, of so many immense projects have as yet been fully appreciated, for such a programme as now envisaged in India, within a very limited time schedule, pre-supposes a certain stage of industrial productivity, and requires collateral development of interlocked industries. The pressing need for food sufficiency is manifest to all, but it may be doubted if this objective is best achieved by such dispersal of activities and resources over so many major unco-ordinated schemes, some of which have already had to be abandoned after immense expenditure of money.

REFERENCES

- Anonymous, (1943, 1949). Economic Geology of Orissa, with a mineral map of Orissa. By Officers of the Geological Survey of India. Cuttack.
- Auden, J. B. (1934). The Geology of the Krol Belt. *Rec. Geol. Surv. Ind.*, **67**, 357-454.
- (1935). Travellers in the Himalaya. *Rec. Geol. Surv. Ind.*, **69**, 123-167.
- (1937). The Structure of the Garhwal Himalaya. *Rec. Geol. Surv. Ind.*, **71**, 407-433.
- (1942). A geological investigation of tunnel alignments for the Jumna Hydro-electric Project. *Rec. Geol. Surv. Ind.*, **77**, Prof. Paper 2.
- (1948). Some new Limestone and Dolomite occurrences in Northern India. *Indian Minerals*, **2**, 77-91.
- Auden, J. B., and Gupta, B. C. (1942). Report on sodium salts in *reh* soils in the United Provinces, with notes on occurrences in other parts of India. *Rec. Geol. Surv. Ind.*, **77**, Prof. Paper 1.
- Auden, J. B., and Dutta, K. K. (1946). The Kosi Dam Project: Preliminary Report. Geological Reports in appendices 10, 11. Central Water Power, Irrigation and Navigation Commission. Government of India.
- Dunn, J. A., Wadia, D. N., Auden, J. B., Ghosh, A. M. N. (1939). The Bihar-Nepal Earthquake of 1934. *Mem. Geol. Surv. Ind.*, **73**.
- Dunn, J. A. (1941). The Economic Geology and Mineral Resources of Bihar Province. *Mem. Geol. Surv. Ind.*, **78**.
- Dutt, A. B., and Ghosh, P. K. (1950). Preliminary Report on Coal suitable for the manufacture of Synthetic Petroleum. *Bull. Geol. Surv. Ind. (A)*. No. 1.
- Gee, E. R. (1934). The Dhubri Earthquake of 3rd July, 1930. *Mem. Geol. Surv. Ind.*, **65**, Pt. 1.
- Middlemiss, C. S. (1887). Crystalline and Metamorphic Rocks of the Lower Himalaya Garhwal and Kumaon. *Rec. Geol. Surv. Ind.*, **20**, 134-143.

- Middlemiss, C. S. (1890). Physical Geology of the Sub-Himalaya of Garhwal and Kumaon. *Mem. Geol. Surv. Ind.*, **24**, Pt. 2.
- Oldham, R. D. (1899). Report on the Great Earthquake of 12th June, 1897. *Mem. Geol. Surv. Ind.*, **29**.
- Pilgrim, G. E., and West, W. D. (1928). The Structure and Correlation of the Simla Rocks. *Mem. Geol. Surv. Ind.*, **53**.
- Watson, E. R. (1923). The production of Sulphuric Acid and Caustic Soda by electrolysis of Sodium Sulphate. *Journ. Soc. Chem. Ind.*, **42** (1), 251 (T).
- West, W. D. (1935). Preliminary Geological Report on the Baluchistan (Quetta) Earthquake of May 31st, 1935. *Rec. Geol. Surv. Ind.*, **69**, 203-240.
- (1937). Earthquakes in India. Pres. Address, 24th Indian Science Congress, Section of Geology and Geography.
- (1939). The Structure of the Shal 'Window' near Simla. *Rec. Geol. Surv. Ind.*, **74**, 133-163.

DISCUSSION

DR. S. K. CHAKRABARTY.—Dr. Auden has rightly stressed on the importance of detailed Geological survey work as a preliminary to the selection of dam sites particularly for examining the seismic activity of the region in general and the exact location of the 'faults' in particular. He has also pointed out that the results derived from the surface data are sometimes in disagreement with the evidences obtained from tunnels and borings. It is, however, well known that in majority of cases the 'faults' cannot be located from surface evidences nor by borings. Recent investigations¹ through sensitive seismographs have shown that the region in the neighbourhood of the Boulder Dam in Arizona, U.S.A., became seismically active after the construction of the Dam and the seismic activity of the region varied in parallel with the water load in the reservoir. The hypocentral depths of these earthquakes were between 4 and 10 kilometers. Geological reconnaissance could not suggest the possibility of this activity as their origin is at a depth which is beyond the normal limits of accessibility of the Geologists. The cost of dam construction over a 'fault' is heavy and should be avoided. The regions where deep-seated 'faults' are in existence although apparently of small activity should also be avoided, since at a later date, influenced by the heavy load of the water in the reservoir, the seismic activity may increase and may lead to serious damage. The possibility of the occurrence of large earthquakes in the neighbourhood should also be carefully explored, and necessary measures should be made in the design and constructions of the different structures. If therefore these precautionary measures are not carefully planned at the initial stage serious damages are liable to occur which may completely damn the Dam projects with heavy loss to national wealth.

It is well known that 'gravity anomalies' are associated with active seismic faults. The alluviated depression of the Ganges fronting the Himalayan arc is often considered as a foredeep of the Pacific type and this when considered with the 'gravity anomaly' recorded in that region suggests that there is a strong seismic belt in that region. The order of seismic activity of that region should therefore be carefully examined before any decision is made regarding the seismicity of the Dam sites.

Unfortunately the seismic instruments at present under operation in India are extremely insensitive and are unsuitable for the study of 'local earthquakes' and 'local structures'. The mere fact that the records taken with these instruments do not show any seismic activity should not be accepted as the basis of site selections and designs. The influence of the type of seismographs available in a region on our knowledge of local seismicity was revealed a few years ago by studies carried out in north-eastern United States. That area had long been considered as a region of rare seismic disturbance, although a few moderately strong shocks did occur in the past with epicentres in that region. Since the installation of short period electromagnetic seismographs at several stations in that area an unexpectedly large number of small 'local' earthquakes are regularly recorded and the earlier conception about the seismicity of the area has completely changed. It is therefore highly desirable that after the completion of preliminary reconnaissance through the study of surface geology, detailed mapping of the local structures is made through Geophysical methods, specially by the seismic methods. Benioff² has shown how the seismic activity of a region is connected with the 'elastic rebound strain increments' associated with individual earthquakes. If therefore the type of 'creep' in a region is calculated from the seismic records, then it may be possible to give a short range forecast about the 'magnitude' and 'origin time' of major earthquakes.

It is thus evident that although in the works of site selection and that of designing different structures, geological field survey is necessary, it is not at all sufficient and geophysical methods should be adopted before any final decision is taken in the matter. The authorities concerned should take special note of the points referred above if they want to make their attempts successful without much strain on our national economy.

DR. J. B. AUDEN remarked, in reply to Dr. S. K. Chakrabarty, that the seismic shocks developed in the Colville basin of Lake Mead began with a short lag, after the reservoir had filled

¹ D. S. Carder, *Bull. Seis. Soc. Amer.*, **35**, 175, (1945).

² H. Benioff, *Bull. Geol. Soc. Amer.*, **60**, 1837, (1949).

for the first time. Subsequently the shocks decreased rapidly in frequency. The shocks arose as a consequence of the suddenly imposed load of water, in the roughly circular Colville basin, upon the earth's crust amounting to 12,000,000,000 tons. In the case of the reservoirs behind the Grand Coulee and Shasta dams, which are long but of small width, very few local shocks have occurred. The shocks do not indicate a crust unstable from still active tectonic causes, but are a consequence of an induced load, the stresses from which have later reached adjustment.

With regard to the second question concerning deep-seated active faults, Dr. Auden said that the primary concern was not so much with the depths to which the faults extended, but as to whether or not the faults are active. Active faults, such as the San Andreas and Haywood faults of California, are naturally of significance to engineers if structures have to be located in their vicinity. On the other hand, dead faults, such as are present in the Gondwana coalfields of India, can be regarded as harmless, and the only concern of the engineers is the actual foundation treatment that may be necessary in the event of a structure being built across them.

Further comments by J. B. AUDEN.—The above reply was handed in before the written text of Dr. S. K. Chakrabarty's questions was available in extended form. On account of the shortage of time available in which to deliver the addresses, which were themselves strictly limited in length, at the Symposium, it was not possible to enter into a prolonged discussion of the matters brought up by Dr. Chakrabarty. It may be pointed out that the geological reports submitted to the Engineers of the Kosi and other projects have taken into account the available evidence from geodetic and geophysical work, seismograph records, and geological surveys. The structure of northern India was discussed in some detail in the *Memoir* which described the Bihar-Nepal Earthquake of 1934, in which we made use of gravity and geophysical work done by the Survey of India (*Mem. Geol. Surv. Ind.*, 73, pp. 118-160; and Survey of India *Geodetic Report* for 1935, pp. 45-63). These data have long ago been placed before the engineers by the Geological Survey of India, and designs for dams have been made with due regard to their position relative to the seismic zone of northern India.

It is true that geological surveys use as data mainly surface exposures, but in many regions it is possible to make a reasonably accurate three-dimensional figure extrapolated to considerable depths, based on the two-dimensional configuration together with the vertical dimension which is well displayed in montane zones. In the Himalaya the vertical exposures extend over a range of 8.0 km. When we come to the Gangetic alluvium, which is a downwarp region with strong negative gravity anomalies, it is admittedly not possible to determine the configuration of the basement of the alluvium merely by surface exposures in the quite flat terrain, but in this case data were available from work carried out by the Geodetic Branch of the Survey of India, which was fully discussed in the *Memoir* of the Geological Survey cited above.

Dr. Chakrabarty remarks that active seismic faults are associated with areas of gravity anomalies. While the epicentral region of the Bihar earthquakes lies in a region of strong negative gravity anomalies, there has been up to the present no means of proving whether or not an active seismic fault lies below the 6,000-7,000 feet of alluvium which underlies North Bihar. Such a fault was postulated by the Geological Survey but is not at present capable of rigid proof. Indeed, the Japanese seismologist Nasu actually considered that the Bihar earthquake had no connection with a tectonic fault (Earthquake Research Institute; Tokyo Imperial University, 13, Pt. 2, pp. 417-432). We are not deductively, on general structural grounds, in agreement with the views of Nobuji Nasu, but the decision regarding the difference in opinion must await further research. Those visible faults in the Himalaya, which are regarded as active and seismic, are not so far as I know associated with any particular gravity anomalies, for they are localized except in linear extension, while the anomalies are regional. The area of the U.P. and Bihar alluvium involved in the downwarp and negative anomalies is of the order of 75,000 sq. miles.

Dr. Chakrabarty considers that it is premature to construct dams in northern India until a complete geophysical survey has been carried out. While admittedly there are many unknown factors, the available knowledge, small though it may be, is considered sufficient for the purpose of advising on seismic factors and undertaking large projects. If construction of dams in the seismic western states of the U.S.A. had been deferred until a full geophysical survey were available, there would still be no dams or irrigation or hydro-electric power in California. A compromise has to be made, and some element of risk must be admitted, in all construction work, both in India and abroad.

Moreover, even supposing that the whole region of northern India had been fully surveyed by a close net of gravity stations, and by seismic and magnetic observations, there would still be some uncertainty about the interpretation of the results. The United States geodesists, working over a limited terrain of 3 million square miles, have concluded that isostasy is almost complete. They are probably correct within their own region, but work in the east and west Indian archipelagos, in India, and elsewhere, shows that very great exceptions exist to perfect isostasy, and the conclusions drawn from the United States do not have universal validity. Much depends also on the nature of the assumptions and what corrections are adopted for the gravity work. In some countries no geological correction has been thought necessary to the gravity data, but Evans and Crompton have shown the valuable results which are obtained by applying a geological correction in northern India (*Quart. Journ. Geol. Soc.*, London, 102, pp. 211-249). These are problems involving global study and correlations, and engineering projects can scarcely wait until the integration of results has been carried out with complete

agreement in every country. Many new seismograph stations will be set up in India as a consequence of the major projects now under consideration, and new and valuable information will thereby be gained *pari passu* with construction. Knowledge is never complete, for research even engenders new problems, requiring new enquiries and interpretation, but to postpone all construction because of the limitations of knowledge would involve awaiting an always receding millennium.

MR. A. ACHARYA.—In view of the importance and urgency of these multi-purpose river projects for which the opinion of the geologists of the Geological Survey of India is necessary, from the preliminary planning stage to the final constructional stage of these projects, I think installation of the following very important laboratories in the Geological Survey of India may be considered very helpful in enabling the geologists to get all possible valuable engineering geology data for their day-to-day problems.

1. *Earth-materials or soil mechanics laboratory* to carry on examination of earth materials from the foundation and embankment, e.g., mechanical analysis of soil; percolation, compaction and specific gravity tests and tri-axial shear tests;

2. *An up-to-date Petrographic laboratory* of the type of that of the U.S. Bureau of Reclamation, Denver, Colorado, U.S.A., for speedy identification of the clay minerals by the X-ray diffraction and micro-chemical methods, etc.

3. *A Concrete Laboratory* to carry out standardized tests on concrete aggregate to determine their quality for use in constructions. These tests include determination of (a) specific gravity and absorption; (b) accelerated soundness; (c) abrasion resistance with the help of an abrasion machine; (d) organic impurities in sand, and (e) properties of standard mortars to find the structural strength of fine aggregate.

It is true that we have laboratories of this type in different parts of India. But considering that promptness and thoroughness of action are the pre-requisites for efficient handling of engineering geology problems, location of such laboratories within easy reach of the geologists would be very useful in obtaining and interpreting engineering geology data and the advice tendered by geologists would then be more authentic.

Secondly, in view of the importance of the multi-purpose river projects and the responsibilities involved therein, it is important that the civil engineering colleges in India should provide adequate orientation courses in geology for efficient co-operation between the engineers and the geologists.

Finally, it may be suggested that a glossary of terms dealing with engineering geology should be prepared by the Geological Survey of India so that geologists and engineers may understand each other in their work.

The President agreed that it would be desirable to adopt a vocabulary which is mutually understandable.

DESIGN

By K. L. RAO, M.Sc., Ph.D., A.M.I.C.E., M.I.Struct.E., M.I.E. (Ind.), Designs Engineer, Central Designs Office, P.W.D. Buildings, Chepauk, Madras.

(Communicated by Dr. S. L. Hora, F.N.I.)

SUMMARY

It is shown that almost all the big river projects in India serve to fulfil a number of objectives and considerable economies can result by careful designs of dams and power plant. Before the detailed designs are made out, it is necessary to carry out preliminary investigations and obtain full data with regard to the amount of river flow, depth of sound rock, overburden soil characteristics and quantities of materials of construction.

Based on these, a preliminary design is made and economy studies are undertaken to select the best suited type of dam for the locality. Detailed investigation then follows and collection of data is completed. Making use of these, detailed designs are then made. Different factors which affect the design of masonry dams and earth dams with special reference to Indian conditions are considered separately. Brief indication is given for stability calculations and design of foundation treatment, galleries, spillway, gates and power units, etc. It is pointed out that proper cut off and drainage arrangements are necessary for ensuring safety of an earth. Model tests are required to confirm the design provisions. Modern construction plant is then considered and recommendations made for what is considered as suitable in India.

The necessity for obtaining field observations in the actual structures is emphasized. It is finally concluded that the designs must be prepared to suit the local conditions. Mechanization is advocated for the earth dams. To ensure efficient and economic designs in India, a central designs office for the whole of India should be established and consolidated in the near future.

CONTENTS

	<i>Page</i>
1. Introduction	443
2. Materials of Construction	444
3. Investigation and collection of design data	445
4. Detailed Design and Specifications:—	
(a) Masonry Dams	447
(b) Earth Dams	450
5. Construction Plant and Programme	451
6. Measurement and Research	452
7. Conclusion	452
8. References	452

I. INTRODUCTION

Formation of reservoirs across rivers by construction of dams usually serves many purposes. The flood water which would have been running to waste is held up and released in regulated amounts. Floods are moderated, irrigation water supplied according to requirements and continuous power is generated. Other purposes served are navigation, silt abatement, domestic water supply and recreational facilities. It may be that all the objects may not be achieved simultaneously but still it is a multi-purpose project which serves more than one object. Grand Coulee Dam (U.S.D.I., 1938) across River Columbia in Washington State, U.S.A., serves to generate two million kilowatt power and to supply water required for cultivating million acres. The Tennessee Valley dams serve the purpose of controlling floods at Cairo, Mississippi and help in generation of 2.6 million kilowatt power and silt removal. Boulder dam is another example where power is generated, floods controlled and irrigation water stored.

Sometimes it happens that only a single object is achieved by the construction of a dam across a river. Thus the Neversink dam in New York State is useful only for supplying water to the City of New York. Galloway scheme in United Kingdom

which consists in the construction of series of dams across rivers Ken and Dee is mainly a hydro-electric project intended to take up the peak loads of Glasgow.

The old river control works in India which consisted mainly of flood banks, alicuts, regulators, diversion weirs or tanks, served only irrigation. Recent projects consisting of storage reservoirs are mainly multi-purposed. Thus the Moyar Scheme under construction is mainly a hydro-electric scheme and consists in conserving water in Ooty hills behind a 112 feet dam in Pykara and utilizing it for generation of power by making use of 600 ft. fall. But the 400 cusecs of water thus let down from the turbines will be available in addition to the waters in Lower Bhavani Reservoir intended to be utilized for irrigation. Similarly in purely irrigation works like Ganga Canal in Hardwar, the irrigation water is made to pass through turbines at all drops in the canal and much needed power is generated.

Great care is to be bestowed on the future possibilities. At Aswan dam no provision was made for penstocks with the consequence that today Egyptians are denied the benefit of development of hydro-power. Penstocks for future power development are therefore made in Malampuzha dam.

Also the possibility of utilizing irrigation water itself for developing power must be studied. A notable example of this is Tungabhadra project where all the irrigation water will be passed through turbines and power generated. Bhakra dam is another instance where 240,000 kw. power will be generated from the water let down for irrigation lower down.

Thus as every major river project in India serves to fulfil a number of objectives, progress towards attaining sufficiency in power and food is simultaneously made with the completion of each of the river projects. Indian rivers and terrain permit the construction of a number of these projects. Only a few have been investigated so far and of these Hirakud, Bhakra, Damodar, Tungabhadra, Lower Bhavani, Gangapur, etc., are under construction. Of the schemes which were thoroughly and fully investigated and not taken up, mention should be made of Ramapadasagar project (across Godavari) and Rihand. Tapti and Krishna Pennar are two schemes with great possibilities and are now under active investigation.

It is evident that there is scope for a very large number of excellent multi-purpose river projects in India and to be able to undertake as many as possible of these with our limited financial resources, it is necessary to evolve economical designs and construct them utilizing methods most suited to our conditions.

A storage project consists essentially of three different parts (1) dam and appurtenant works, (2) power plant, and (3) canal system. Sometimes the canal system costs as much as the other two or even more but still there is not much scope for effecting economy in its design as it is completely influenced by the local conditions. Hence economy is to be achieved mainly under the first two items, i.e. dam and power plant. Further the design of the canal system has been well established in this country and due to limitations of space in this paper, the design of dam and power plant only has been considered.

2. MATERIALS OF CONSTRUCTION

Dams are built of masonry or earth according to the suitability of the site.

Concrete masonry consisting of stones of sizes up to 6" or 9", cement and sand is extensively used in Europe and United States for the construction of their dams. There are two reasons for this. First, great speeds are attainable with concrete. Thus at Grand Coulee dam, 20,000 cubic yards per day was attained many times whereas in Aswan or Mettur dam where stone masonry was employed, the maximum outturn never exceeded 1/10 of the above figure. The second reason for using concrete is the great cost of labour. Complete mechanical plant is developed for construction of the dams with concrete while no such plant is available for building dams in stone masonry.

In India, both the above reasons are practically absent except in a few cases, like Bhakra or Ramapadasagar where due to great possibility of floods, speed of construction may have to be accelerated. Otherwise, in most of the cases use of cement concrete seems to be unnecessary. By using cement concrete, a large number of complications arise. Cement on hydration with water, produces heat and if this is not dissipated by radiation or convection in the thick mass of concrete, heat is locked up and it takes years before it is lost. But when the temperature comes down, the huge mass shrinks and causes cracking of the structure many years after the construction. To reduce the effects of heat of hydration steps have to be taken as indicated later in 4—1. But all these troubles can be minimized by using stone masonry. In the construction of Tungabhadra, Lower Bhavani, etc. stone masonry only is employed. It is important to note that when cement is used for stone masonry it is desirable to use medium cements. Manufacture of this cement is similar to that of normal cements, the only difference being extra grinding and addition of ferric oxides to reduce the percentage of tricalcium silicate.

In the construction of Mettur dam a portion of the cement in the mortar was replaced by surki or burnt brick powder (Barber, 1940). This was found to result in a large amount of beneficial effects such as reduction of cost, reduction of heat of hydration and reduction of permeability. Mr. Blanks (1949) has stated recently that the addition of an admixture is the only solution for securing durability of structures using cement. This practice of adding surki to cement is followed both in the Lower Bhavani and Tungabhadra dams.

While engineers in Madras State utilized cement in the construction of the dam, Hyderabad and Mysore engineers have scrupulously avoided cement. Lime-surki sand is used in Hyderabad, while lime-surki alone is used by Mysore engineers (Sampathiengar, 1946). Even today in the construction of Tunga dam (40' high) lime-surki only is being used. This successful use of lime mortars has led to great controversies about the comparative efficacies and economies of lime mortars and cement mortars. This controversy reached a climax in deciding on the mortars in Tungabhadra dam, which is a joint concern of Hyderabad and Madras States. It was agreed that cement mortar is to be used for spillway portion of the dam, while lime-surki mortar is to be used for the other portions.

It has to be conceded in favour of lime-surki mortars that its use will enable dispensing with all transverse joints. But where strengths in excess of 30 to 40 tons per sq. ft. are required great care is to be bestowed with lime-surki mortars. Tests give very erratic results and unless lime-surki are standardized and uniform results are obtainable as with cement, it will be difficult to push on with the use of lime-surki mortar in important and high dams.

Where concrete is used, it is necessary to note that pebbles and round stones can be used as aggregate. This is one of the notable lessons brought out by the use of round stone called 'gravel' by Americans in the construction of their dams. U.S. Bureau of Reclamation avoids using crushed stone and prefers always the round pebbles which are obtainable from the ground in western states of that country. Sand used may be either natural sand from the river bed or crushed sand as in Pykara dam.

For earth dams puddled clay is being used for the interior till now in India, modelled after the British practice. But now the use of soils with clay content ranging only from 20 to 40% with controlled moisture content is advocated.

3. INVESTIGATIONS AND COLLECTION OF DESIGN DATA

3—1. *Preliminary Investigations*

It is necessary that as much data as possible must be collected before designs are started. The data include the flows in the river, rainfalls in the project area, weather data, the silt content of the waters, geological features at site, depth and

nature of foundation rock and availability of materials of construction and transport facilities. In trying to find the depth of rock without much of expensive drilling, two methods are used in India. If the overburden soil is sandy, penetrometer method gives quite often useful results. The method consists in driving $1\frac{1}{2}$ " mild steel rods to which conical shoes are fitted loose, by dropping 100 lb hammer through 30 inches. The number of blows required per foot of penetration is noted and graph drawn. From the diagram it is easy to note the relative density of soil and rock level. In Ramapadasagar investigation penetrometer was very successfully used, 300 points having been put down during investigations. In Ramapadasagar and Kistna Pennar projects, geophysical prospecting was done. The method consists in letting down electric current through two electrodes at some distance apart and measuring the electrical resistance and potential drop between third points. From a series of these observations it is possible to calculate the depth of the rock. This method is said to have been used with great success at Rolling Fork and Round lake both of Mississippi in America (U.S.W.E.S., 1943) though it has not yielded similar useful data at the sites investigated in Madras State. Intensive hydrologic studies are made to arrive at the maximum floods and the total amount of annual run off, making use of the observed gauge readings, flood marks, slopes, etc. and the unit hydrograph method (Greager, Justin and Hinds, 1944) and the intensity of rainfall methods.

Making use of the preliminary data, a rough design is made out usually based on similar structures elsewhere. The storage capacity and height of dam are fixed by considerations of requirements and condition of area which will be submerged. It sometimes happens that a particular important town may get submerged and in order to avoid this the storage capacity is reduced with a loss of economy. Curves showing reservoir capacity vs. height and area of submersion for some Indian dams are shown in Fig. 1. The location and type of construction adopted for spilling the excess water have a large influence on the economic aspects of the project. It is sometimes necessary to construct part of the dam in earth and part in masonry. It is thus in the preliminary stage of designs, various types are tried with a view to obtain as economical a structure as possible.

3—2. *Detailed Investigations*

Completion of the preliminary stages of investigation and design may bring out the type of the dam and the material of construction that will in all likelihood be used at the selected site. The detailed investigations are now undertaken for finding depth of sound rock sub-surface soil conditions and the availability of the material of construction. The cores of the rock are obtained either by caly drill or diamond drills. Diamond drills are used up to 3" providing cores of $2\frac{1}{8}$ " and generally for larger holes shot drills are used. In the latter, though drilling speeds are less, the cost per foot is lower. In important places where rocks present shattered or laminated appearances, tunnels of 36" diameter or more are also put in horizontally and inclined to study specially the abutments. In very rare cases vertical holes 3' dia. are drilled so that the inspecting personnel can go in and examine the strata of rock.

It is very essential to carry out tests to find out the sub-surface condition of the over-burden soil. This becomes specially important in earth dams. Samples of soils both disturbed and undisturbed are obtained from different depths and the characteristics (U.S.D.I., 1948) such as the size, gradation, strength and permeability are determined. Various tests are done on the materials to find out the suitability and specially for detecting the deleterious minerals in the composition. For earth dams number of trial pits are put in the reservoir water spread area, soils taken out and analysed for their suitability in the construction of different zones of earth dams. Soils with clay contents 20 to 40% are usually selected for inner core while the rest of the soils are used for outer zones. The qualities of the materials available for each type are accurately determined to aid in arriving at the section of the dam. Pumping

tests are usually conducted in which observation of the draw down and the rate of the pumping are observed. This will enable the overall coefficient of permeability of the soil to be obtained. Silt content of the water and periods of occurrences are carefully recorded so as to help in calculating the life of the reservoir. Observations of the temperature of the river water and air, humidity and wind velocity help in drawing up an accurate programme of construction.

4. DETAILED DESIGN AND SPECIFICATIONS

4-1. *Masonry Dams*

Types and Dimensions: Sections of some of the masonry dams under construction in India are shown in fig. 2. The gravity type is almost generally used and is suitable for many locations. Where the site is narrow and less than 1,500 ft. arched type may be considered. Sometimes arched gravity type is used as in Boulder dam. In Sweden, buttress dams are most favoured. Reinforced concrete dams are scarce.

The top width of dam varies according to requirement of traffic on top. It is 26' for Tungabhadra dam and 18' 6" and 10' for Malampuzha. The height of the dam above maximum reservoir level varies between 5' and 10' and is dependent upon the fetch of the water and velocity of the wind. The modern tendency is to keep the front face vertical or with batters not exceeding 1 in 5. The rear is made up of either one or more slopes generally averaging between .65 and .8 slope. Fig. 3 shows cross-sectional areas of some Indian and foreign dams.

Stress and Stability computations

The selected section is subjected to complete stress analysis and computations are made for normal, shear and principal stresses at different elevations. All these computations are based on the hypothesis of *Bouvier* and *Unwin* who assume that the plane of principal stresses are present at right angles to the resultant and the batter of the face respectively. The stress at the heel and toe under different conditions of reservoir empty and reservoir full with and without uplift are calculated. Where there is possibility of seismic disturbance, the stress computations should take account of it. For Ramapadasagar dam an earthquake acceleration of 0.1 g. and 1 second period of vibration have been allowed. Limit of pressures depend upon foundation rock and materials of construction. Generally maximum intensity allowed for the lime mortars range up to 10 tons per sq. ft. and cement concrete up to 25 tons per sq. ft. Fig. 4 shows the heights *vs.* maximum calculated stresses in some of the dams.

Stability computations are made to determine the ratio of overturning and resisting moments and factors of safety of 1.5 to 3 are aimed. Sliding factor (U.S.D.I., 1946) should not exceed 0.8.

The above method of calculating the stresses in a dam is not very satisfactory so that model tests and, different theories (Bey, 1947) appear from time to time trying to evolve a correct method of calculation. The gravity dams are calculated assuming the dam as a cantilever on a rigid base but as in reality the foundation has the same elasticity as the dam, new methods such as slab analogy (U.S.D.I., 1938) are employed in calculating stresses. As a result of these studies it is now established that the shear stresses are non-linear at the base and remain so to a third of the height of the dam.

The gravity dams when spanning across the steep and narrow gorges will act both as a beam across the two abutments and as a cantilever. The method of calculating stress in such a structure is known as twist analysis (U.S.D.I.). These studies generally indicate an increase or decrease of about 15% in the maximum stress at heel and toe.

Foundation Treatment

The designer must take careful account of the foundation rock. The rock is never universally sound. It will present considerable variations and difficult problems due to cavities shear fractures, shattering joints, etc. occur. Thus in Madupatty dam the whole bed rock was conglomerate even up to depth of 100 ft. below bed. At Porunchani there was conspicuous shear zone resulting in shattering and kaolinisation in the middle of the river. Pockets of talc schist embedded in gneisses presented difficulties in Lower Bhavani. Intrusions of pegmatite and epidiorite rocks gave rise to difficulties in Tungabhadra; anticipated clay gorges in Bhakra are expected to offer special problems to the engineer. Treatment of the foundation problems differs but it may be said that the general practice is to scoop out the weak zones to depths depending on height of dam and backfill with concrete.

Consolidation grouting and pressure grouting have become universal phases of dam construction at present to strengthen foundation rock against leakage (Simonds, 1947). One of the modern methods of attaining greater safety of stability is to provide adequate drainage to lead off the leakage water. In low dams the drainage is collected by means of drains $9" \times 18"$ and led out at intervals. The most universal practice in all the medium and high dams is to drill drainage shafts and lead out the water through open drains in the foundation galleries. The foundation gallery is generally $5' \times 7\frac{1}{2}'$ and is located parallel to foundation rock with a minimum cover of 5 to 10 ft. above the bedrock. In concrete dams for purpose of pressure grouting the joints and cooling the concrete it is usual to have galleries at about 50' height interval.

Joints

Dams built of lime-surki are not provided with any joints. Thus Krishna-rajasagar dam though 8,600 feet in length has no joints, but where cement is used joints are provided at intervals ranging between 50' to 150'. In Mettur dam, joints are spaced 126 feet. The object of these joints is to provide for movement in dam in either expansion or contraction and localize cracks due to initial shrinkage of cement concrete or masonry. Where cement concrete is used and base width of the dam is more than 150 to 200, it is necessary to provide longitudinal joints in a zigzag fashion. These joints must be grouted later. Grouting the transverse joints is done in American practice but has been omitted in masonry dams in India. On the water side of the joints, some sort of arrangement to prevent leakage of water is always made. The most usual one is the provision of copper strip with or without asphalt seal.

Spillway and energy dissipation

Provision is made in a dam for surplussing floods which may occur once in 100 years. In important structures sufficient waterway is provided to pass down floods of even great intensity. Careful attention has to be paid for flood moderation effect of the reservoir and consequent reduction of the peak flow. The top of overflow section is generally built curved either of parabolic shape or of 2 or 3 circular arcs. The aim in this type of construction is to enable the easy flow of water and thus increase coefficient of discharge. Considerable attention is paid to investigate the cavitation pockets. Usually this is done by hydraulic model tests. The dimensions and shape of the spillway dam depends on the type of controlling gates. The falling waters possess considerable energy and may easily cause erosion pockets at the rear. To obviate this danger rear protection work consists in the provision of one of the following (Davies, 1942):—

1. Cistern;
2. Baffle blocks of different types and provision of long aprons;
3. Shooting buckets.

Sometimes the flood waters are discharged through sluices and siphons either of the saddle or of volute types as at Hirabasagar dam.

Gates

Gates are provided for controlling the spillway and sluices. The spillway gates (Schoeklitsch, 1937) may be of lift, radial or drum type. Sometimes roller types are also adopted. Of these the radial gate is the cheapest and the drum the costliest, while from the point of easiness of control and operation, drum gates possess many advantages. For Lower Bhavani radial gates are proposed while for Tungabhadra lift gates are provided.

The design of the gates for sluices presents difficulties due to the high pressures involved. In rapid flowing waters, cavitation occurs and to nullify its effect, special design features are incorporated. Ample provision for admission of air in rear of gates is made. Constrictions at outlets and bellmouths at the inlet or other contrivances are now adopted. Staunching devices to prevent leaking of water consist of special types of rubber seals. Metal to metal contacts usually provided so far have now practically become obsolete.

Concrete Dams

Special precaution has to be taken in the design and construction of concrete dams. Provision is made for abstraction of heat of hydration (Rowhouser, 1945). This consists in embedding 1" dia. pipes at 5 foot intervals vertically and horizontally and circulating cold and refrigerated water through them. All the American dams are built nowadays with this type of cooling arrangement. Besides this the other steps adopted are (1) use of modified or low heat cements; (2) provision of joints longitudinal and transverse at distances not more than 50 feet; (3) restricting the lift of construction to 3 to 5 feet every 3 days; (4) sprinkling the aggregates with water and addition of ice in place of mixing water to a limited extent.

Power Units

Practically every dam in India unless the reservoir is a very small one, will develop power in addition to irrigation. This power developed may however vary from month to month. It is best to develop power by passing the irrigation water through the turbines. Calculations are made to find the power developed in different months and duration curves are drawn. Power that will be continuously available throughout the year is calculated and machines are provided generally of twice this capacity to meet the peak load demands. The powerhouse is built of either R.C. frames or steel structures. The spacing of the machines and other details are calculated from well-established practices. The water is led into the machines through steel penstocks embedded in the dam. The machine may be either vertical type or horizontal though in modern practice horizontal types are almost eliminated. For emergency shutting off of the water, emergency gates operated by electric switches are installed. In big dams the gates are operated by automatic hydraulic hoists. The turbines generally are of Kaplan type up to heads of 70 feet and Francis type up to 900 feet. For cases when the variation in maximum and minimum water level is great, movable blade type is used. The location of switchyard sometimes provides difficulty due to terrain condition. They may have to be located on the top of the powerhouse as in *Bonneville Dam* or between powerhouse and the dam or on the top of the hill as in *Boulder Dam*.

In French dams like *Aigle* and *Saint Etienne Cantales* the powerhouses are located under the spillway, due to want of spaces for the spillway elsewhere. In Sweden, it is almost universal practice to construct powerhouses in tunnels so as to avoid damage in the event of an air attack.

Navigation and fish passes

Sometimes it may become necessary to provide for the continuity of navigation and passage of fish from downstream to upstream side of the reservoir. A notable example of a dam where such provisions are made is the Bonneville in U.S. But most generally provision of these is costly and careful economy studies must be made before incorporating any of the features. Specially in the case of very high dams, it may become necessary sometimes to provide navigation not by the usual lock chamber system but by providing the lift of the ship itself and its transfer bodily by cranes. This was intended to be done in the Yangtze project in China.

4—2. Earth Dams.

Earth dams are more economical than masonry dams, though they involve quantities, 10 to 15 times specially in flat country where the depth of sound rock is great. They are constructed by hydraulic fill or rolled fill methods. The former is practically very little used now. Depending on the availability of pervious and impervious materials different types of zoning as shown in figure 5 are designed. The soils of the foundation materials and borrow pit areas are thoroughly examined and the data obtained used in calculations. Change of ideas with respect to use of puddled core for the inner hearting is mentioned already. Similarly during construction earth is to be laid with convex top sloping outwards and not inwards as in olden days.

Stress and Stability calculations

Stress calculations in earth dams are based on highly uncertain methods. Perhaps the only acceptable calculations would be that pertaining to the pressure distribution in the foundation soil by Boussinesque theory. For testing the stability of the dams Swedish circle in original or modified form is used (U.S.D.I., 1948), and a minimum factor of safety for stability is fixed at 1.25 for sudden draw down condition.

The success of present earth dam is more or less entirely due to the great advance in construction methods (Creager, Justin and Hinds, 1944). By laying earth at controlled moisture contents, by rolling out completely in layer of 6" to 8" with sheepfoot rollers generally (though in humid climates like England smooth rollers are said to be equally effective) and by adopting generous slopes and top widths, safe earth dams are assured. One of the most important details that must be attended to is the provision of proper cut off. This becomes specially important where the foundation soil contains lenses of permeable soils. The difficulty met with in Fort Peck is due to insufficient safeguards against percolation. Though sheet pile cut off was provided water escaped to the rear, built up pressures and began to raise the ground on the downstream. To relieve this, relief wells were constructed at every few feet intervals and the water allowed to drain out freely. Various types of cut off are allowed. These may be (1) R.C. caissons as in Neversink and Merriman Dams (B.W.S.C.N.Y., 1941); (2) wall constructed of interlocking sheetpiles; (3) Trenches as in Anderson Ranch Dam; (4) Masonry or concrete diaphragm walls. There must be ample provision for drainage of earth dams. This is usually done by providing reverse fillers consisting of graded sizes of gravel in the rear portions of the dams. In small dams drainage may consist of longitudinal and transverse drains formed out of tiles.

In the construction of high earth dams it is most essential that good rock protection should be given both for upstream and downstream faces. The upstream riprap serves to withstand the waves while the downstream rock will enable drainage and provide sufficient weightage for stability. The depth of riprap may vary from

18" to more than 3'. All stones are dumped and very rarely hand packed. Indian practice is to provide revetment 12 to 18" thick on the front side and turfing on the rear side.

In Hyderabad State very successful attempts have been made in which earth dams with masonry facings are constructed. The masonry wall can be founded on any type of foundations and will be much less in size than a masonry dam. See fig. 6.

Special care must be taken in the provision of spillway and sluices in earth dams to prevent water creeping along the sides of sluices, care must be taken by providing a number of cut off collars. Control in placement and consolidation is obtained by repeated density-in-place tests and Proctor's needle resistances. The pattern of flow of water through earth dam is dependant on soils, consolidation and time. The hydraulic gradient is usually taken as 1:4 line. This is not quite correct and the actual experiments will show that the gradient line is not straight but curved of either convex or concave types. Also it takes number of years for the water in embankment to build up and hence the gradient line varies from time to time. Besides this, water in the pores of the clayey soil presents another problem. Due to weight of earth on the top and rolling the pressure inside the pores may easily build up thus reducing the intensity with consequent loss of shear strength. The failure of clay banks during construction is due to this pore pressure. It is a happy augury that pore pressure gets reduced in course of time. One of the serious danger for the stabilization of upstream slope comes from the sudden draw down. The pressure of water gets locked up in the pores with the consequence that the weight is reduced and slip occurs.

Earth dam design involves therefore careful watch of the material of construction and altering the design to suit the dam.

5. CONSTRUCTION PLANT AND PROGRAMME

A modern masonry or earth dam involves utilization of a large amount of mechanical plant (Ackerman and Locher, 1940). Thus in a masonry dam shovels and drag lines are required for excavation of foundation and handling spoil earth. Crushers are used to pulverize the rock to required sizes, screens are employed to get the required sizes and belts are freely used for conveyance of materials. (Fig. 7.) In Shasta Dam rubber belts conveyed stone and sand from a distance of 13 miles. The materials are taken to batching plant, weighed mixed and delivered automatically. The concrete is then conveyed either on the ropeway or on trestle bridges by making use of the hammerhead cranes, the buckets containing the mix are taken to any position of the dam and concrete laid. This kind of complete mechanization is possible only in concrete dam. In stone masonry dams, artifices may be employed for conveyance of materials but for actual handling of stones and placing them in position equipment has yet to be invented.

In earth dams, earth is dug by shovels or scrapers, conveyed in wagons or by belts and rolled in place by sheepfoot rollers. (Fig. 8.) If the moisture is too high, burners are sometimes employed to dry them up as was done at Horseshoe Dam in U.S.A.

In India, utilization of mechanical plant in earth dam construction has resulted in considerable economy. Excellent example of this is Gangapur dam near Nasik. Provided well-established maintenance shops are made available, mechanization can be introduced with great profit in earth dams in India.

Taking into account the various local conditions the designs engineer must draw up well co-ordinated programme of construction. He has to study the river diversion problem, the possible rates of outturn of concrete, masonry, earth and rate of supply of cement and other material of construction.

6. MEASUREMENT AND RESEARCH

Designs as finalized in the office may have to be altered due to the new information obtained as the work proceeds. Careful account of all the alterations has to be maintained. One of the methods of securing economy in future designs or construction is to obtain field observations on stresses uplift pressures temperature and other movements that occur in a dam from time to time. In earth dams, information on total settlement and settlement consolidation by foundation treatment and bank material is to be collected. Similarly the pore pressure in earth dam and seepage water is to be determined. To make all the observations, necessary equipment such as strainmeter, electric thermometers uplift pressure meters are available (Raphael, 1943). The field observations will serve a double purpose. They provide a check on the performance of the structure and enable data to be obtained which can be used for subsequent construction.

7. CONCLUSION

A rapid survey of the scheme of design of a dam and power plant is given in the paper. It will be evident that considerable economy of cost can be effected by careful designs to suit the local conditions and utilizing the local materials.

While part mechanization is advocated in the masonry dam, complete mechanization seems justified in the case of earth dams.

The designs of dams are done either by Governmental organizations or by a firm of consulting engineers. All the designs for big dams in America are done by Federal Bureau of Reclamation at Denver, T.V.A. at Knoxville and American Army Engineers at Washington D.C. Moderate and small dams such as those built for water supply for New York are designed by consulting Firms. In India at present there is no unified procedure. Each state is preparing its own designs with and sometimes without the help of firm of consultants. For some river schemes the designs are being prepared by CWINC organization in Delhi.

Considerable prosperity for parts of the country was the result of great irrigation works on Krishna, Godavari and Ganga in the middle of the last century. If this prosperity is to be multiplied and made universal for the whole country, the middle of this century must see the completion of many multi-purpose projects.

I am obliged to the members of Central Designs Office, Madras, for help in preparation of this paper and to Shri A. R. Venkatachari, B.E., M.I.E. (Ind.), M.Am.Soc.C.E., I.S.E., Chief Engineer, Madras, for permission to present the paper.

8. REFERENCES

- Ackerman, J. A. and Locher, C. H. (1940). Construction planning and plant. Barber, C. G. (1940). History of the Cauvery Mettur Project, 334.
- Blanks, Robert F. (1949). The use of Portland-Puzzolan cement by the Bureau of Reclamation. *Journal of the American Concrete Institute*, 21, 89-108.
- Board of Water Supply of the City of New York (1941). Specifications and drawings for the sinking of two exploratory caissons for the Neversink Dam.
- Greager, Justin and Hinds (1944). Unit Hydrographs. *Engineering for Dams*, 1, 158-178.
- (1944). Details of Earth Dams. *Engineering for Dams*, 3.
- Davis, C. V. (1942). Scour protection below overfall dams. *Handbook of Applied Hydraulics*, 347-351.
- Loliavsky Boy (1947). Sazillism: Its origin and evolution. *The Engineer*. May 2, 9, 16, 23 and 30 of 1947.
- Raphael, J. M. (1943). Strain measurements in Shasta Dam. Second progress report. Installation of embedded instruments. United States Department of the Interior, Bureau of Reclamation, Denver, Colo.
- Rawhouser, C. L. (1945). Cracking and Temperature control in mass concrete. *Journal of the American Concrete Institute*. Feb.
- Sampathiengar, M. C. (1946). A short note on surki mortar. Annual Report. Hydraulic Research Station, Krishnarajasagar.

- Schocklitsch, A. (1937). *Hydraulic Structures*, do. 2, 582, 667.
- Simonds, A. W. (1947). Foundation and contraction joint grouting Ramapadasagar Dam.
- U.S. Department of the Interior, Bureau of Reclamation, Denver, Colo. (1938). *Grand Coulee Dam. Dams and control works*, 28-43.
- U.S. Department of the Interior, Bureau of Reclamation, Denver, Colo. (1948). *Earth Materials—Test Procedures*.
- U.S. Department of the Interior, Bureau of Reclamation, Denver, Colo. (1946). *Manual 3, Part 5. Storage Dams—Chapter 2: Gravity Dams. Design and construction handbook*.
- U.S. Department of the Interior, Bureau of Reclamation, Denver, Colo. (1938). *Slab Analogy experiments, Part V. Technical investigations Bulletin 2*.
- U.S. Department of the Interior, Bureau of Reclamation, Denver, Colo. (1948). *Treatise on Dams. Chapter 8. Earth Dams*.
- U.S. Department of the Interior, Bureau of Reclamation, Denver, Colo. Trial load method of analysing twist effects in gravity dams. *Technical Memo. No. 570*.
- U.S. Waterways experiment station, Vicksburg, Mississippi (1943). *Seismic and resistivity—Geophysical exploration methods. Tech. Memo. No. 198, 1*.

DISCUSSION

M. B. RAMACHANDRA RAO said that since one or two of the previous speakers have made some reference to the application of geophysical methods in Engineering project investigations, I wish to add a few remarks to clarify the position.

We have already been using geophysical methods—especially the Electrical Resistivity method, in a few projects, to aid in the investigation of the bed-rock problems. Some engineers think there is a lot of merit in the method, and a few others hold that the results obtained by the geophysical method are useless and even misleading. But from personal experience, I could state that the results we have obtained in a few of the projects have been generally encouraging and have proved to be of some definite use to the engineers. The results which are usually stated to be misleading are in reality proceeding from the unsuitability of the actual conditions in certain particular cases for a successful application of the geophysical method. Most of the geophysical methods can be applied only on an indirect basis, and it is not always possible to give precise data concerning the sub-surface features. Nevertheless, there often exist enormous differences in the physical properties between the alluvial formation and the bed-rock, and by using appropriate technique of measurements clear indications of the sub-surface bed-rock topography may be obtained. The method should not, in any case, be looked upon as capable of furnishing the exact depth to bed-rock at any given point in the sense that a bore-hole is able to furnish. It should not also be thought that drilling can be entirely dispensed with, if geophysical methods are employed. At best, the geophysical indications can give only an idea of the order of depth to bed-rock in the area. After a feasible site is selected extensive drilling will have to be carried out for checking the results of the geophysical survey and preparing the designs and estimates. It is in the exploration of alternative sites, that the drilling methods become too slow and very costly. A direct probing even by means of the simple penetrometer method spoken of by Dr K. L. Rao, is usually costlier than the geophysical methods. However, the penetrometer can be used only in loose sands, and even so the results can be sometimes misleading.

The geophysical methods played some part in the preliminary investigations of Ramapadasagar project.* Prior to 1944, some boreholes had been put down which showed that the alluvium in the bed of the Godavari river extended to a depth of some 200 feet. For the dam, more than nine alignments—each of them a mile or more long across the river—in a strip of country covering a length of some 12 miles, were proposed for investigation. The problem of finding the depths to bed-rock in this large area solely by drilling methods was a formidable job, and would have taken a lot of money, and many years to complete the work. The exploration of the bed-rock topography by using the electrical resistivity method was carried out at a very small cost and within three months.

Although the electrical resistivity methods proved useful in the investigation of this project, as also in the investigation of the Gandikota and the Somasila gorges of the Pennar river, I would like to emphasize that the Seismic method would have given us far more satisfactory results, not only in the estimation of the depth to bed-rock but also in furnishing useful information on the compactness of the rock from the calculated data on the rate of transmission of elastic waves. We have not been able to use this method for want of suitable instruments, but attempts are being made to get them from abroad.

The geophysical methods can be particularly helpful in locating hidden structures such as faults, shear zones, and vulnerable geological contacts in dam sites, tunnels and waterways, where rock formations are covered up by thick soil, debris, or alluvium. The preliminary

* Geophysical Investigations for Selection of Site for Ramapadasagar Dam across the Godavari River in Madras, South India, by M. B. R. Rao, *Trans. Amer. Inst. Min. and Met.*, Vol. 181 (1944), pp. 68-98.

examination by geophysical methods might help in properly orientating the detailed investigations for the project.

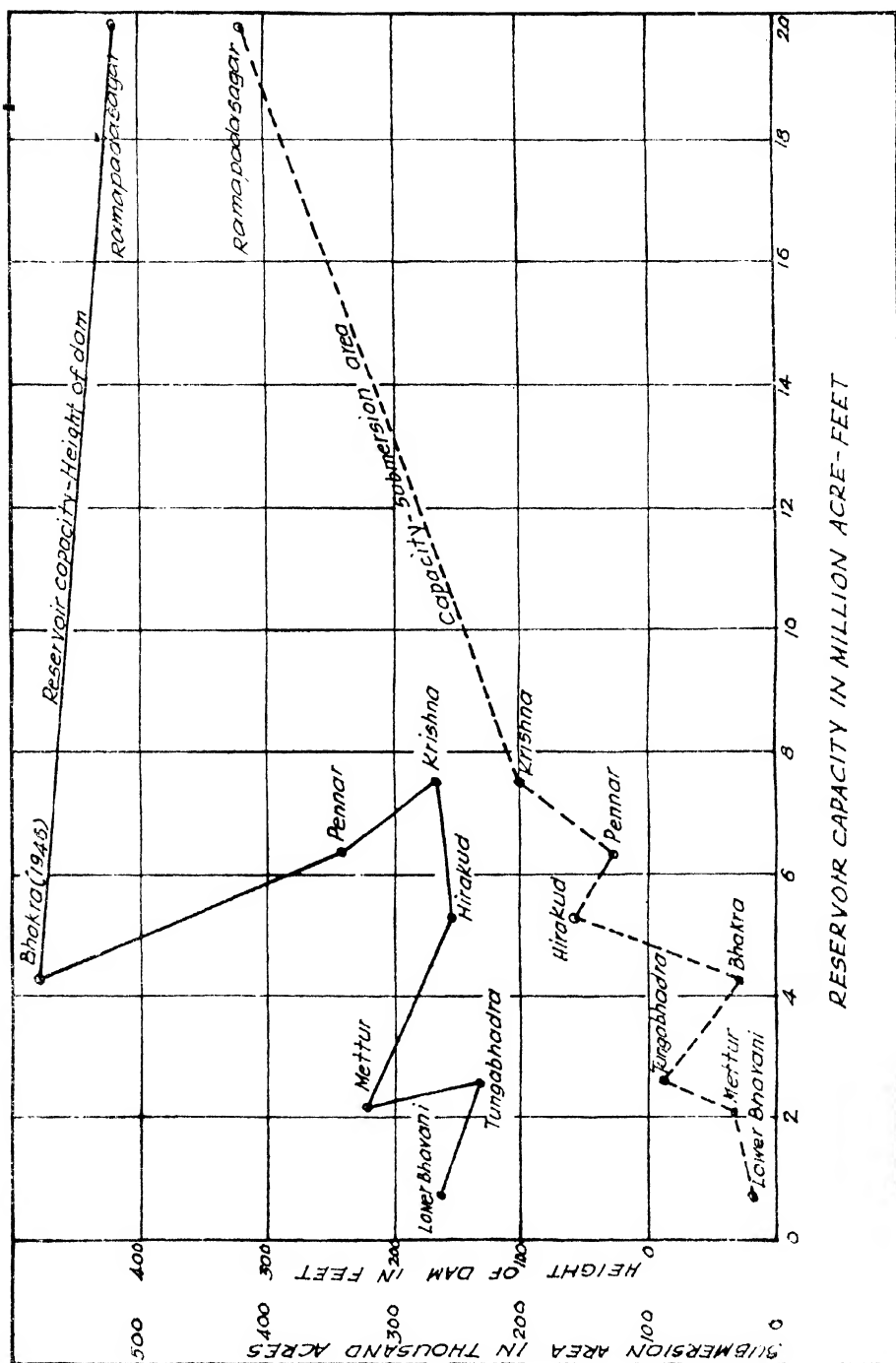
Furthermore, the geophysical methods could be used in the river valley projects for the location of concealed deposits of sand, gravel, clay, etc. required as construction materials. In the United States of America the Bureau of Public Roads, the Army Corps of Engineers, and some of the State Surveys have been using geophysical methods. A few of the Bureaus have their own geophysical staff to carry out the investigations regularly. In India too, there has been an increasing appreciation of the usefulness of the geophysical methods in project investigations, and the Geological Survey of India has been carrying out the geophysical investigations whenever the application of these specialized methods is called for.

Mr. K. K. DUTTA pointed out that while many speakers have discussed the importance of planning and designs in multi-purpose river development projects, none has said anything about the importance of procedure, and the care and precautions necessary during construction. The multi-purpose projects envisage major constructions like dams, weirs, barrages and powerhouses. Masonry, concrete or earth-fill will be used in different structures. In these constructions, specifications concerning concrete, the properties of cement and aggregate, may be found out by research. Further, the nature of the available soil materials, and the proportions in which they will be mixed, as well as the procedure of laying, and amount of rolling necessary, will be suggested by the soil mechanics expert. It should also be regarded as imperative that the stipulations given by the specialists are actually adhered to during construction. He pointed out from his experience of different dam sites in India, that excavation down to a sound foundation, and the treatment of these foundations before masonry or concrete are placed, is essential for their safety. Careful supervision in all these stages of construction is very important.

Dr. S. L. HORA commented on two statements made by Dr. K. L. Rao in his remarks—utility dams and history of dam-construction dating as far back as exactly one hundred years so far as South India is concerned. As regards utility dams, there are Tamil, Telugu and Canarese inscriptions which show that irrigation tanks were started by the Pallava kings as early as the 6th century A.D. Up to the 11th century, there is no mention of any other purpose for which these tanks were constructed, though in a Tamil inscription dated 1010 A.D. there is a mention of fishermen, showing thereby that fishery of these tanks was also exploited. In the beginning of the 12th century A.D. we find a treatise on angling and fish-culture in tanks by Someśvara in *Manāsollāsa*. In all the Tamil inscriptions of 14th to the 16th century A.D., we find that the fish-lease money was considered sufficient for desilting and repairing the tanks. Thus from a unipurpose utilitarian irrigation tank we find the evolution of a multi-purpose irrigation-cum-fishery tanks as early as the 14th century A.D.

Dr. N. R. DHAR: Many speakers have emphasized that India will be able to produce much more food when the multi-purpose projects are completed. The food position, however, is extremely difficult due to the large increase of population year after year. Since 1911 the production of cereals like wheat, rice, jawar, bajra, ragi, in India and Pakistan, has remained constant, in spite of the drive of 'GROW MORE FOOD CAMPAIGN'. The annual cereal production is 60 million tons per year. The world production of cereals today is nearly 600 million tons. If the cereals produced in the world were equitably distributed, each human being living in this world would have nearly 3,200 calories per day. The world production of potatoes, milk, meat, fish, vegetables and other better food materials is approximately 400 million tons per year. In other words, the amount of cereals on which the oriental people subsist and which is produced in India and Pakistan, is only one-tenth of the world production, whilst the population of India and Pakistan is approximately one-fifth of the world population. It is clear, therefore, that India is terribly underfed. This position cannot improve very much even by an increased irrigation and the supply of nitrogen plant food materials because of the compensating agent, that is, the large increase of population.

There is a very important consideration which has not been touched so far. It is well known that the water retention capacity of a soil is controlled by its organic matter content. Soils in tropical countries are poorer in organic matter than soils in temperate countries. Roughly, the organic matter content of Indian soils is one-third or one-half of soils in cold countries. Hence, when rain water or flood water falls on the soil, it runs off far more readily from our soils than in cold country soils. This is a very important point which has to be taken into account in calculating running off water. The most important need of soil improvement is to increase the organic matter.



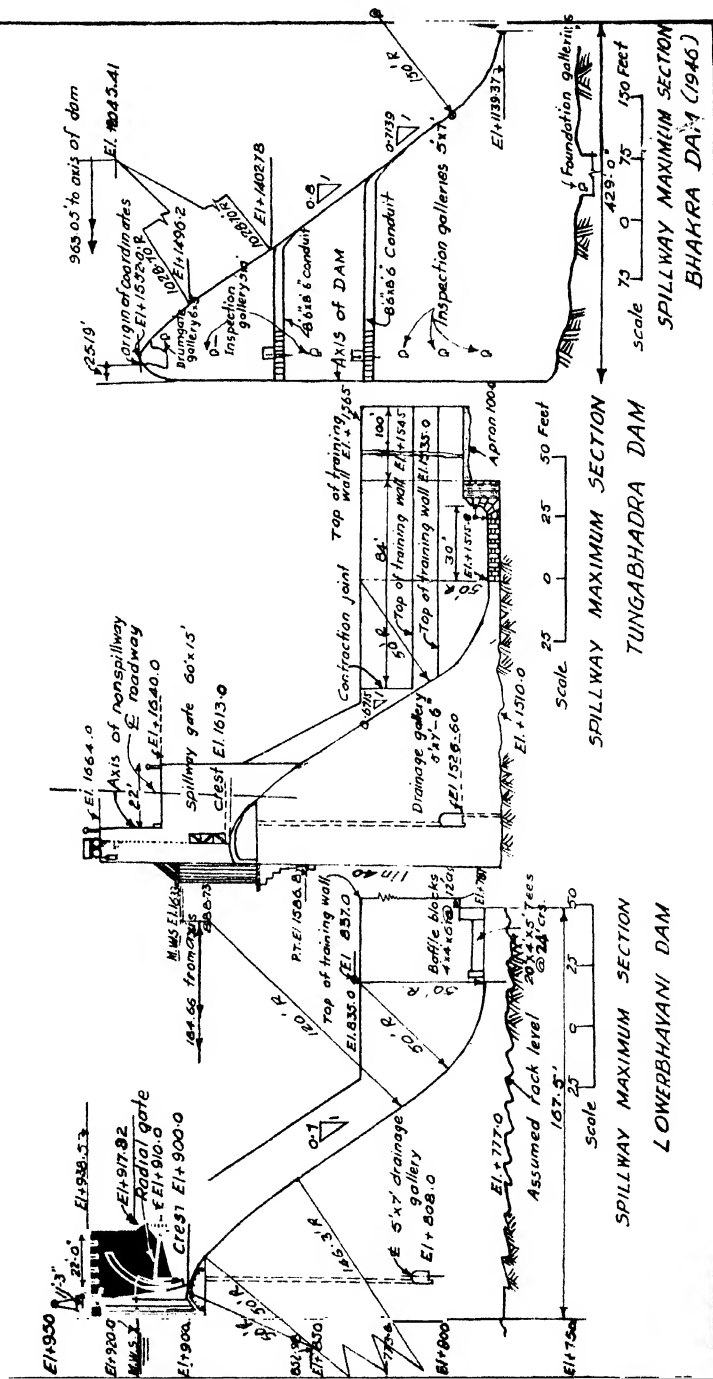


FIG. 2. TYPES OF MASONRY DAMS

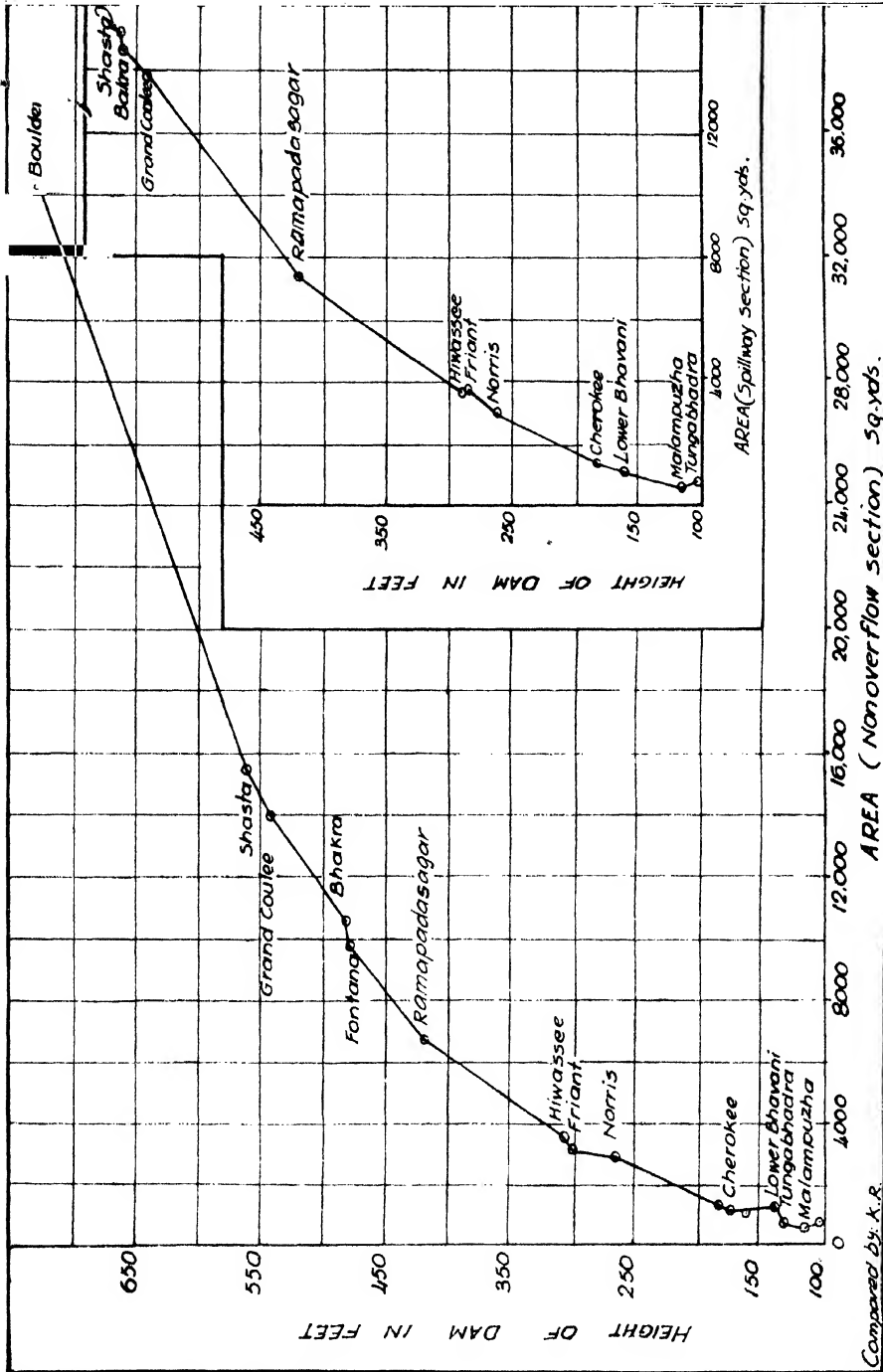
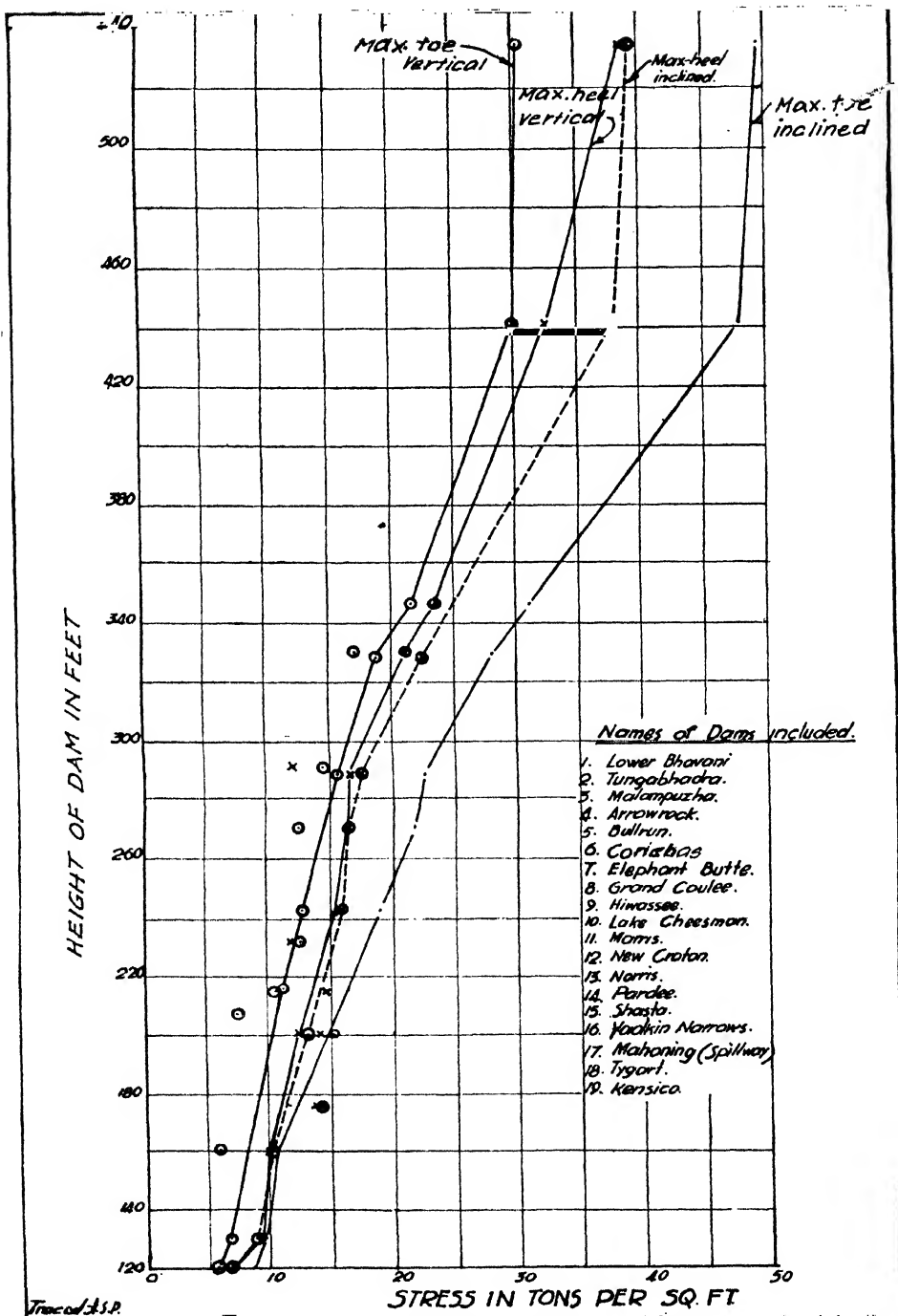
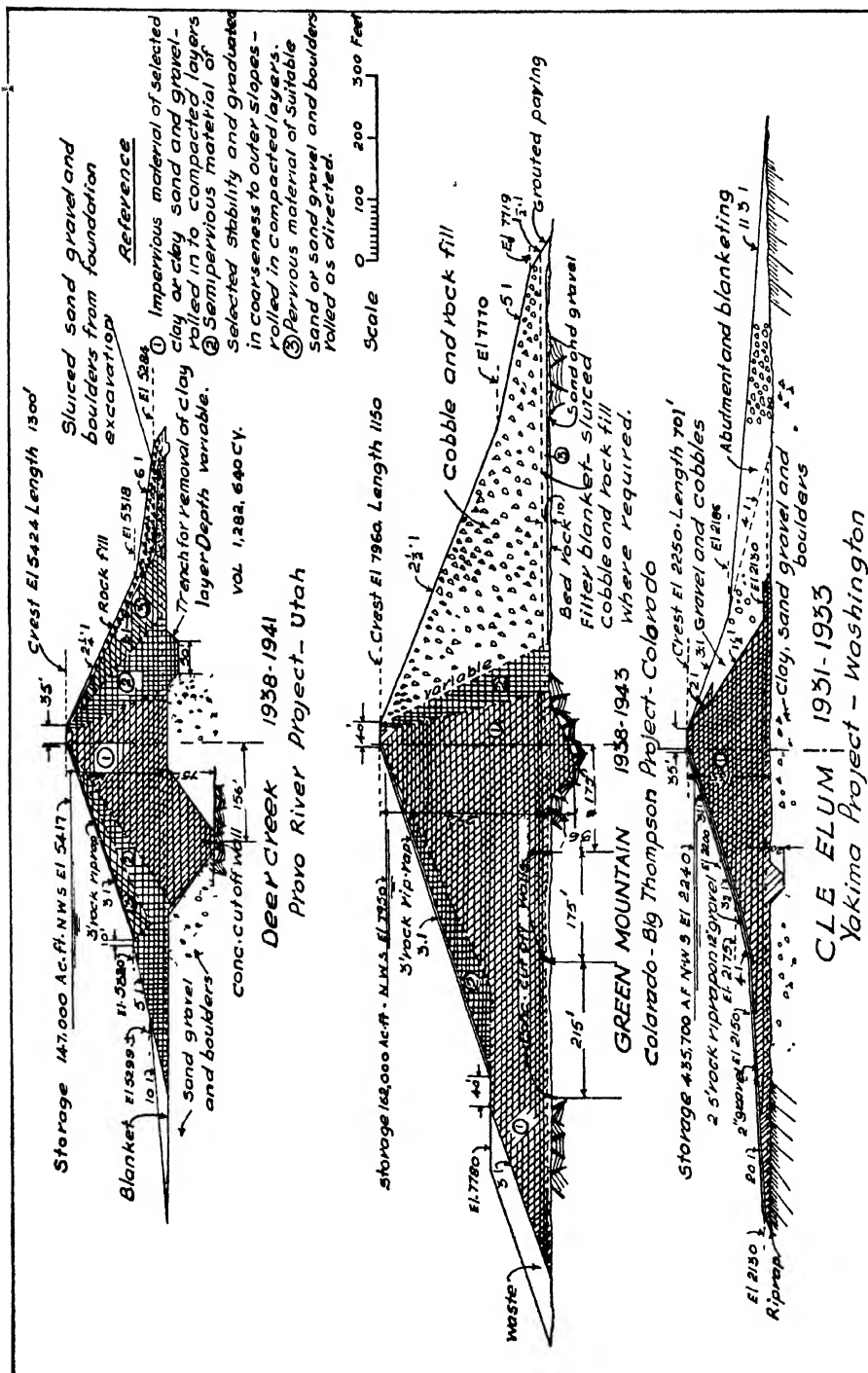
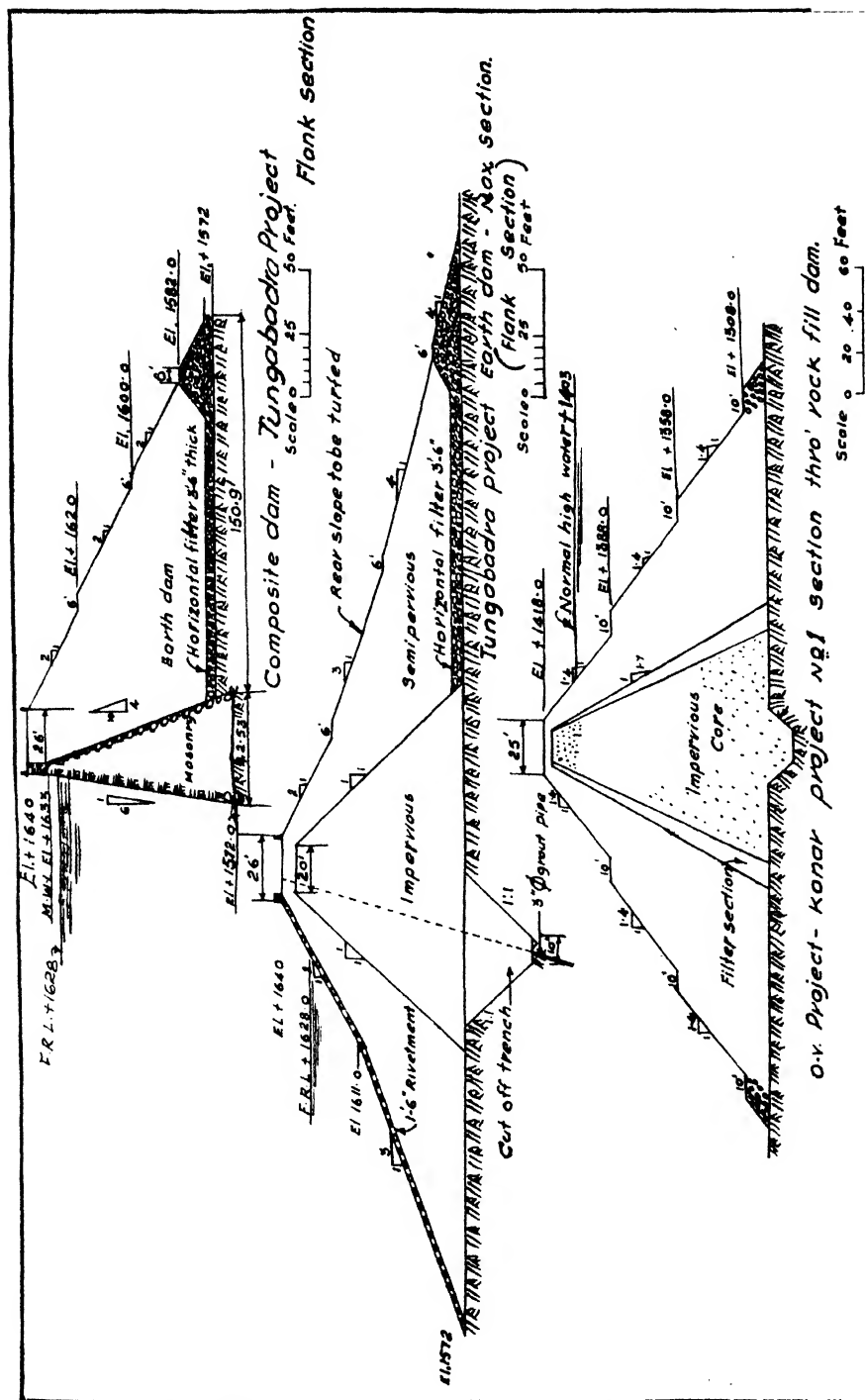


FIG. 3. AREA OF SECTION Vs HEIGHT.







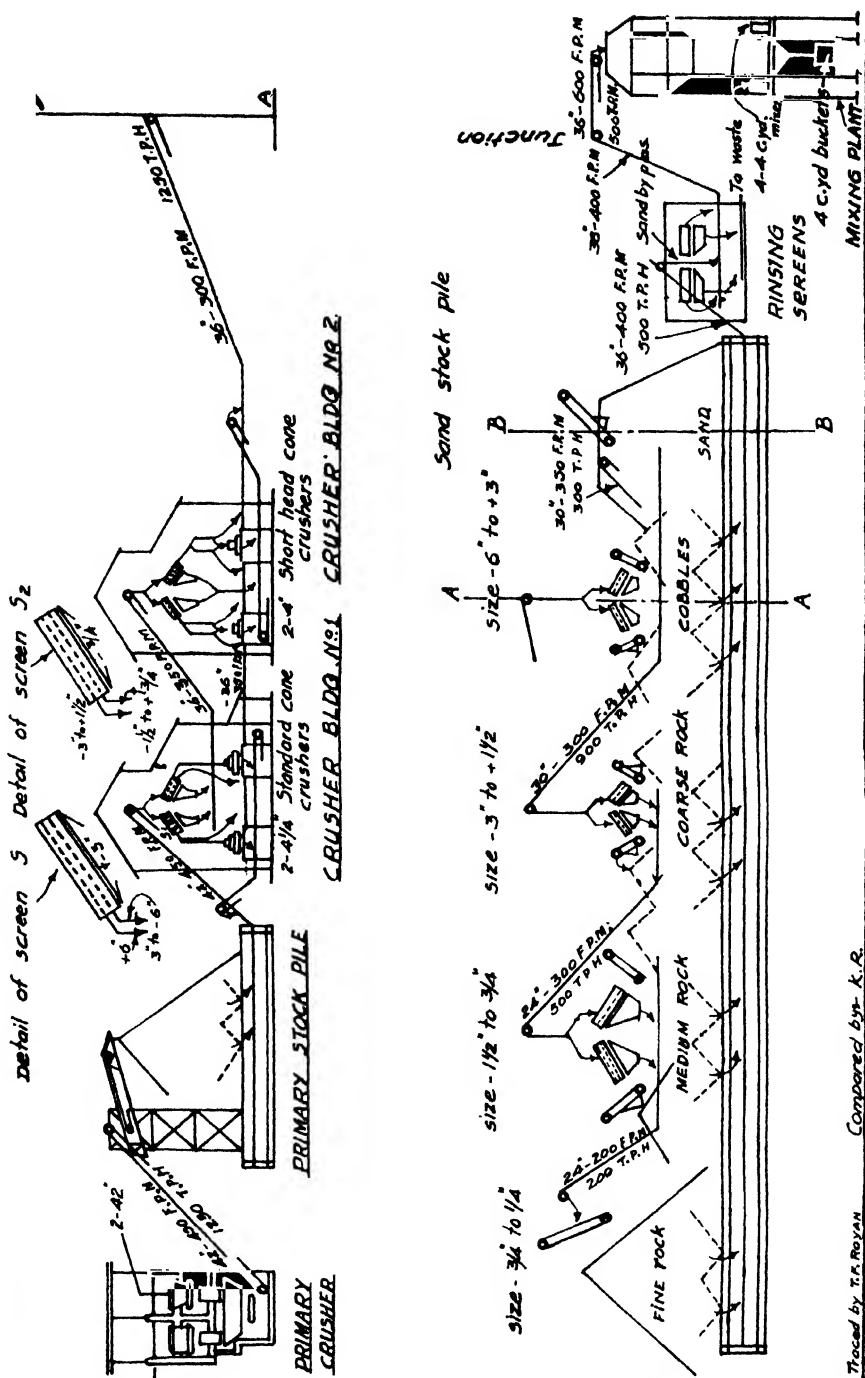




FIG. 8. Tournapull brings soil and Sheepfoot roller consolidates it.

FLOOD CONTROL

By **A. C. MAJUMDAR, I.S.E. (Retd.)**, Consulting Engineer to the Government of West Bengal, Calcutta

(Communicated by Dr. W. D. West, F.N.I.)

SUMMARY

The problem of flood is intimately connected with the problem of river conservation—conservation not only of the river channel proper but also of the rainfall within the catchment area. The method devised by nature for this purpose consists of absorption by the subsoil of a substantial portion of rainfall thereby reducing the run-off which not only reduces the intensity of floods and soil erosion but, being gradually released by percolation, maintains the river flow throughout the year. It is interference with this natural economy by destruction of forests and other harmful acts that is responsible for most of our river problems, particularly flood problems. A certain amount of interference is inevitable owing to pressure of population and to meet the growing needs of civilization, giving rise to a conflict between the needs of the river and those of man. This should be resolved with the aid of our advanced scientific knowledge and research.

Flood control measures can be broadly classified as (a) preventive and (b) remedial. The former aims at restoring the natural economy by efficient preservation of forests and other measures designed with the object of reducing the rate of run-off and preventing soil erosion and are more important as they deal with the flood problem at its source. Of the latter, flood-embankments are very common, but having regard to their evil effects fully discussed in the main paper, they cannot be recommended except for the protection of important vested interests. Among other remedial measures, the most important are flood moderating reservoirs. They are not, however, likely to be financially feasible unless the objective is widened and the reservoir is designed on a multi-purpose basis so as to develop and bring for the use of man potential river wealth in its various aspects, such as irrigation, navigation, power, etc. These objectives are not conflicting but complementary and are essential for raising the economic standard of the people.

For optimum development, our rivers should be treated as individual units irrespective of political boundaries. In the new constitution, power has been given to the Government of India to legislate in respect of inter-State rivers and a Bill will shortly be placed before Parliament. Some suggestions are offered in the main paper as to the organizational and legislative requirements for efficient conservation of our rivers and their optimum development on a multi-purpose basis so that necessary provision may be made accordingly in the proposed Bill.

Flood problem is intimately connected with the problem of river conservation—not only of the river channel proper but, what is perhaps more important, conservation of the rainfall within the catchment area. Nature's method for the conservation of rainfall as compensation against its erratic distribution is to have the precipitation partly in the form of snow if there is any catchment area at sufficiently high altitude, and what is more important, to absorb into the subsoil and store underground a substantial portion of rainfall which while reducing the run-off and the intensity of floods, maintains the river flow by percolation throughout the year when there is no rain and no surface flow to maintain it otherwise. The utility of a river to serve our various needs mainly depends on this compensating action provided by nature which, again, depends on the condition of the catchment, i.e. whether it has sufficient area under vegetation, particularly deep forest, which retards run-off thereby reducing the intensity of floods and their silt-content, and increases the portion of the rainfall which is absorbed and stored underground to maintain the river flow by subsoil percolation during the dry weather. It is interference with this natural economy by destruction of forests and by other harmful acts in the catchment areas and in the river channel that is responsible for most of our river problems, particularly the flood problem. To meet our growing needs, we want regular supply of water but by our action, we are making the distribution of river flow already faulty, still more irregular. This adversely affects all the fields of water uses and particularly aggravates the flood problem. Apparently, there is some conflict between the needs of the river and those of man as with the growth of population certain amount of interference with nature's economy is unavoidable. Room

has to be found for the growing population, while their needs from the land including the forests, now rapidly increasing with the progress of civilization, have to be met. This cannot be stopped but the process should be rationalized with the aid of our advanced scientific knowledge, by intensive study and research, so as to effect a reconciliation between these conflicting interests.

Flood control measures can be broadly classified under two categories: (a) preventive and (b) remedial. As prevention is better than cure the former are more important, such as efficient preservation of the existing forests, afforestation where possible, rational land management, contour trenching and bunding and terraced cultivation along hill slopes, all designed with the object of reducing the rate of run-off and preventing excessive soil erosion. They attack the flood problem at its source and help in reducing the intensity of flood, improving the dry weather flow and, at the same time, owing to less silt charge of the flood water, help in conserving the river channel by natural action. These measures, which do not involve much of capital expenditure but mainly require organizational effort including research and legislation, will, in my opinion, help considerably in reducing the depth of flooding to a safe level. This, while permitting the land building activity of the rivers to proceed, gradually raising the land and fertilizing it, will at the same time, maintain the drainage system in fairly efficient condition due to scour of the silt in the river beds by the clear water drained back from the land. In deltaic area, which is the region mainly affected by floods, this is how the rivers maintain themselves in nature and the aim of controlling measures should be to allow these beneficial activities of the rivers to function, subject to the depth of flooding being reduced to a safe level.

Remedial measures are measures designed with the object of controlling the flood after it has entered the river with a view to minimizing flood damages as far as possible. The most common is the construction of marginal flood embankment and as the deterioration, it causes to the river channel and the drainage system, in public health and productivity of the soil, takes years to manifest itself, it has hitherto been accepted as an effective protection against floods. If it were possible to imagine a river with non-erodible boundary and carrying no silt with the run-off from the catchment basin, embankments would certainly have been a permanent remedy against floods: but the problem is complicated by the all-important silt-factor, viz. the silt which the river brings from its catchment basin as also the silt which it picks up from its erodible boundary on the way. In the economy of nature this silt is intended to be carried with the flood spill so that it could raise and fertilize the land and reduce the silt content in the river-channel to what its velocity could transport. Confinement of the flood within the river by means of embankments disturbs this arrangement and a portion of the silt in excess of what the river can transport, deposits in its bed gradually reducing its carrying capacity. This causes higher and higher flood level to carry the same volume of flood necessitating higher and stronger embankment. So the deterioration of the river proceeds until a stage is reached when it is no longer possible to offer protection against floods by means of earthen embankments.

Embankment, therefore, offers no permanent solution to the flood-problem. At best, it is only a temporary expedient and puts off the evil day to future generations when owing to various vested interests created, and due to deterioration in the drainage system, in public health and productivity of the soil in consequence of the stoppage of beneficial flood spill from the land by embankments, problems are created which are almost insoluble. Even as a temporary expedient it can hardly be considered as a sufficiently effective protection as it is impossible to avoid breaches in earthen embankments and the destructive effect of concentrated discharge through breaches is more serious than gradual inundation, specially as the flood level relatively to the land gradually rises as a consequence of the embankments. It no doubt takes years before the evil effects of embankments are actually felt: this very fact makes

them rather risky expedients, as vested interests are created which stand in the way of any bold solution being adopted in future.

In Bengal, where the flood embankments were perhaps constructed the earliest in India, their evil effects are being felt rather seriously as in several parts, tracts formerly healthy and prosperous have now become hot-beds of malaria owing to the deterioration of the drainage system; land is lying fallow owing to the growing decrease in the productivity of the soil and population is declining. In the deltaic tracts of East Bengal, on the other hand, where there are no embankments and the land is annually inundated by the beneficial flood spill of the Ganga and the Brahmaputra-Jamuna rivers the people are healthy and prosperous. Not having any false sense of security, as would be given by the flood-embankments, they have their houses built on earthen mounds above flood-level and follow agricultural practices suitable to the flood conditions. In fact, this area is one of the richest agricultural tracts in India. Having regard to our experience in Bengal construction of flood-embankments cannot be recommended, except perhaps for the protection of important vested interests where there is no other alternative.

This has no doubt been written on the basis of my experience particularly in deltaic Bengal and there are also instances where beds of embanked rivers have already risen higher than the country level. It appears that the condition of embanked rivers in China is not better and perhaps worse in the case of the Yellow river of which the bed is reported to have risen about 4 metres above the adjacent countryside. Another important evidence as regards the evil effects of embankments that has recently come to my notice relates to the capital of Assam built several centuries ago in the Brahmaputra valley near Sibsagar by the late rulers (Ahom kings) of Assam. The area which was protected by flood embankments is now a big swamp several feet lower than the surrounding country level and it is impossible to drain it by gravity. This has undoubtedly been caused by the stoppage of land building activities of the river within the embanked area which, in consequence, has remained at the same level or has probably been lowered due to surface erosion caused by the local rainfall, while the surrounding land subjected to inundation by the silt-laden flood and the river-beds have been gradually raised.

Conditions obtaining in other countries are not definitely known. But in view of the simplicity of the design and construction of earthen embankments and the fact that their evil effects are not felt till after a long time, and consequently the people are tempted to take recourse to them for their immediate benefit, often reclaiming the land prematurely particularly in tidal areas, they are likely to be very common in deltaic areas. It is, however, possible that owing to the differences in climatic conditions and particularly differences in the silt charge of the flood water their evil effects have not been quite similar. Having regard to the seriousness of the position briefly referred to above organized effort on international level is urgently required so that experience gained from various countries can be compared and after critical study of the data collected necessary action can be taken, keeping in view not only the immediate benefit to be derived from these embankments but also their ultimate evil effects as regards health and productivity of the soil on which will depend the well-being of the future generations.

Other remedial measures that can be considered are:—

- (a) Provision of adequate openings in the railway and road embankments and removal of obstructions to the free flow of flood water;
- (b) Provision of flood escapes;
- (c) Improvement of spill and drainage channels; and
- (d) Construction of flood moderating reservoirs.

The aim of (a), (b) and (c) is to reduce the depth of flooding and its duration by efficient drainage. They permit land building activities of the rivers in the deltaic area to continue, which as explained before, being part of nature's economy, should be

allowed as far as possible. Combined with adequate preventive measures referred to previously, they might even provide adequate protection against flood-damages unless the deterioration of the river and soil erosion in its catchment basin have already reached an advanced stage necessitating recourse to (d) in addition. Having regard to the heavy cost of flood moderating reservoirs, however, prudent course would be to take timely action with regard to the preventive and other remedial measures so that their necessity may be avoided as far as possible.

The object of flood moderating reservoirs is to impound a portion of the flood temporarily and release it gradually, thereby reducing the intensity of the flood to what the river channel below can safely carry without causing any damage. Reservoirs constructed with such a limited objective cannot, however, be financially self-supporting, as more protection of an area from flood can hardly be expected to yield any substantial revenue. If, however, the objectives are widened and the reservoirs are designed on a multi-purpose basis so as to include development of the potential wealth of the river in other respects as well, as far as practicable, such as navigation, irrigation and power, the revenue derived from the various sources might make these projects financially feasible, if not actually productive. For this reason, multi-purpose Reservoir Projects are now finding favour in India, particularly having regard to the immense benefits that are being derived from similar development of the Tennessee river in the United States of America under the direction of the T.V.A. Fortunately, these objectives are not conflicting but more or less complementary as the water impounded within the reservoir while relieving flood congestion lower down the river can be utilized for power generation, irrigation and navigation purposes. These latter objectives will no doubt require permanent storage: but as they are all revenue-producing the extra cost involved can more than be recouped. Besides, having regard to our economic backwardness in India which is attributable primarily to the long neglect in developing our natural resources, the development of our potential river wealth, which India undoubtedly possesses in plenty, is essential for raising the economic standard of the people.

But whatever may be the objective, whether it be flood-moderation alone or the other objectives are also combined, the first and essential requirement is efficient conservation of the river. Within the limitations imposed by nature in the matter of erratic distribution of rainfall over which we can have no control, we must try to stimulate the compensating action provided by nature by rational treatment of the catchment basin already explained, so as to equalize the river flow as much as possible. Secondly, where the possibility of utilization of this fluctuating daily river flow has already been exhausted as in India, to meet the ever-increasing demands for water uses, in the various fields, particularly in irrigation rapid expansion of which is urgently necessary to be able to feed the rapidly growing population, we must go in for storage schemes, i.e. impounding portions of the floods which now run to waste, often causing extensive damages and utilizing the same to supplement the river flow when it is otherwise inadequate to meet our various needs. The storage schemes being usually rather costly their revenue-producing potentialities in the various fields should be developed to the maximum extent possible so as to make them financially feasible, or in other words, they should be designed as comprehensive multi-purpose schemes embracing as many of the objectives of stream control as may be technically and economically feasible.

Technical feasibility of reservoirs, however, depends on the availability of suitable sites which are only found in the hilly portions of the river valleys where there may not be sufficient scope for utilization of the water and which may be beyond the jurisdiction of the political units where such utilization is not only possible technically and economically, but is also necessary to ensure sufficient revenue return against heavy financial commitment that has usually to be made in executing these schemes. This raises a number of complicated problems regarding loss of land to be submerged by the proposed reservoirs, water-rights and equitable apportionment

of the water which have to be solved to the satisfaction of all concerned before any progress can be made. Hitherto, this has been one of the major obstacles in the way of our proceeding with the river development projects as rapidly as could be desired and making the country self-sufficient as regards food. As most of our major rivers flow through more than one state many of our important development projects have been held up for years due to lack of agreement in the above respects among the different political units concerned.

A fundamental point that emerges from the above review is that both for general conservation as also for optimum utilization of their water, including flood-control, which are essential for raising the economic prosperity of the people, rivers should be treated as individual units irrespective of political boundaries so that comprehensive plans may be made for each major river basin, giving due consideration to the rights and needs of different political units, maximum possible development of the river potential and also their economic utilization. Hitherto, the Government of India had no constitutional power to ensure observance of this fundamental principle by legislation. This power has, however, been given in the new constitution and a comprehensive Waterways Bill will be placed before Parliament shortly. I should like to take this opportunity to express my views as to the organizational and legislative requirements for efficient conservation of our rivers and optimum utilization of their water on multi-purpose basis for due consideration in drafting the Bill.

As regards the organizational requirement, it does not seem to be desirable to entrust responsibility for river conservation solely to individual states who are directly benefited by its exploitation. In that case, having regard to the natural tendency to minimize and even ignore the adverse effect on the river so long as its exploitation brings in immediate benefit, nothing substantial will really be done. Though the ideal arrangement would appear to be to entrust this responsibility to the Centre it is not likely to work efficiently in practice as the task will be much too unwieldy for a single organization, having regard to the large number of rivers to be conserved in this sub-continent. Besides, co-operation of the states, particularly the local knowledge of their technical staff appear to be essential. It is therefore suggested that Inter-State Organizations consisting of representatives of interested states and of the Centre with adequate statutory powers and resources should be formed, ultimately one for each of the major river basins, to undertake responsibility for conservation and, as regards initiative, also of exploitation of rivers. In a large basin like that of the Ganga, it will also be necessary to create regional authorities for execution and maintenance of important inter-state schemes. The necessary co-ordination between the different regional authorities will have to be effected by the Main Basin Organization and as between contiguous Basin Organizations by the Centre. Necessary provision should be made in the proposed Bill to enable the Union Government to constitute these bodies with adequate powers and resources. With regard to the latter, it is suggested that a cess should be levied on the fruits of exploitation of rivers (irrigation, navigation and power) and placed at the disposal of the Basin Organization to finance the conservation measures.

Provision should be made in the proposed Bill for quick settlement of inter-state water disputes. The following principles are also suggested for consideration and inclusion in the Bill. The Union Government should have powers to authorize construction of schemes considered necessary in the interest of social welfare and general progress of the country even in spite of the opposition of recalcitrant minorities subject, of course, due regards being paid to the legitimate rights and obligations of the various riparian states concerned. These rights and obligations should be defined in the Bill in principle. For instance, apart from the right of prior appropriation which has to be conceded, right over the balance of water-resource available in any particular river-basin should be governed by the needs of the various riparian states and the obligations should include :—(a) rational treatment of the catchment

basin under the general control of, and, perhaps with a subsidy from the Main Basin Organization referred to above; (b) general control by this body, as regards broad outlines only, of schemes initiated by any state which involves extraction of substantial quantity of water from the river; and (c) finally as regards inter-state river development schemes, giving due facilities for their investigation, execution and maintenance.

To prevent sabotaging of promising schemes indirectly by any state, the proposed Bill should also lay down definite principles to regulate land compensation and rehabilitation. For this purpose, provision in the L.A. Act should form the basis of compensation subject to the right of appeal to the Supreme Court. Some concessions within reasonable limits seem justified for rehabilitating large numbers of displaced population in the case of reservoir schemes. In this connection, the Engineer also has an obligation to reduce the area of permanent submersion by the reservoir to the minimum extent possible, particularly as regards cultivated and culturable waste lands. Loss of food by permanent submersion of cultivated land in the interest of irrigation and flood control can certainly be justified as the loss will be recouped many times over by the project. But in view of the acute food shortage in the country, large additions to the submersion in the interests of power alone can hardly be justified. Production of hydel power is certainly necessary but in the interest of our food economy, loss of cultivated and culturable land should be avoided as much as possible, as making the country self-sufficient as regards food should be given the topmost priority in all our activities. Subject to the above remarks, the people who will have to be unavoidably displaced by the reservoirs should have the right to demand rehabilitation at the cost of the project in lieu of cash compensation. But subject to their present economic standard not being lowered which should be treated as the minimum, standard of rehabilitation should be so fixed that the cost may not materially exceed the money compensation as assessed under the L.A. Act. If any state wants a higher standard being fixed for rehabilitation as a part of general rural uplift, it should be prepared to bear the extra cost.

A further suggestion that occurs to me for reducing the extent of rehabilitation is that, provided the local condition is favourable the acquisition within the reservoir area may be limited to full supply level with perhaps a little margin, as the higher land which will be submerged only temporarily for a few hours at a time during the passage of floods is not likely to suffer any material damage but may even benefit by occasional flushing with silt-laden floods. The present agricultural practice in the latter area need not be interfered with though the homesteads will have to be shifted and houses re-erected on higher ground close by above the designed flood-level, at the cost of the project. This is all the more necessary as the modern tendency is enormously to increase the design flood. Though the probability of its occurrence is rather remote, having regard to the magnitude of the damage that would be caused by the failure of a dam, the engineer has to make necessary arrangement for its safe disposal. But this does not necessarily mean provision of costly flood-gates to be imported from foreign countries, apart from uncertainty of the delivery position during the present grave international situation. Nor would it be justified to incur heavy expenditure on river protection works below the dam as such a catastrophic flood, if it ever occurs, must necessarily be of very short duration. In my opinion, it should be sufficient if these works are designed to suit the highest recorded flood with some margin. For disposal of still higher floods all that seems necessary is to strengthen the dam profile so as to suit the design flood level and allow the flood to rise temporarily and gradually spill over the dam. In this process of rising, the flood absorption capacity of the reservoir will also be enormously increased which will reduce the peak rate of flood spilled over the dam and consequently its destructive capacity lower down considerably more than if it were attempted to work the reservoir to a fixed level at F.S.L. and dispose of the floods by controlled gates.

NAVIGATION

By SARDAR MAN SINGH, I.S.E., Member, Central Waterpower, Irrigation and Navigation Commission, New Delhi

(Communicated by Dr. S. L. Hora, F.N.I.)

SUMMARY

Most of the important rivers of the country were navigable almost all the year round till about the middle of the last century. With the construction of railways and big irrigation works, inland navigation began to be neglected. Railways were allowed to gain monopoly in the field of transport. Rivers were tapped for irrigation without regard to the adverse effect of withdrawals on the navigability of the channels below. Conservancy of waterways not so affected was also neglected except in areas where alternative means of transport were not feasible. Enough attention to the problems was not paid even in such regions.

This neglect appears to have been confined to India alone. In other countries, especially of the West, it was at about that time that inland navigation began to receive more attention. Great works of improvement were undertaken in France, Belgium, Germany, etc. The experience in such countries has been that great industries got set up along the waterways and water-borne traffic grows to tremendous volumes.

River transport in general is much cheaper than any other form of transport. Experience in India during the last war has shown as to how precarious it can be to depend on any one form of transport in emergencies. Both for strategical and economical reasons inland waterways of the country have, therefore, to be improved so as to be navigable.

Partition of the country has raised further problems. The natural waterways of the country on the east have got cut up and inter-communication between parts of India through them has become difficult. Although both Pakistan and India are signatories to the Barcelona Convention, difficulties have been experienced in moving goods from one part of India through Pakistan waterways to another. These emphasize the necessity of planning projects which will enable the difficulties to be overcome.

Hitherto the training works have been designed to improve the channels to accommodate existing out-of-date craft. Owing to lack of incentive, no improvement in the design of craft, both indigenous and foreign, has taken place during the last century. This will have to be remedied and more rational designs of craft introduced.

There need be no fear of water transport becoming a competitor of road and rail transports. There are certain types of cargoes which for economic reasons are best carried by one or the other mode of transport. As both rail and road systems of transport have been nationalized, it will be essential to plan improvement in water transport on the basis of co-ordination.

Withdrawal of water from rivers for the purpose of irrigation is essential. The only means, therefore, of improving navigability of channels is to plan for storing water during the periods in which it is in excess to be utilized both for irrigation and navigation during the periods when the natural supplies are lean. Projects for improvement of waterways have, therefore, to be planned on a multi-purpose basis.

Most of the projects now under construction have navigation as one of the important features. Important ones are Damodar in Bihar and Bengal, Ganga Barrage in Bengal, Hirakud in Orissa and Kakrapar in Bombay. Possibilities of extending inland navigation are vast. It will be feasible to connect the western and eastern coasts of the country by means of channels capable of being navigated by crafts of fairly deep drafts.

History of inland navigation in India for the last one hundred years or so is the history of neglect of water transport and the country's magnificent waterways which used to be navigable almost all the year round. On the Ganges, according to *Thornton's Gazetteer* of 1854, steamers used to ply as far up as Garhmuktesar, about 400 miles above Allahabad. And up to Kanpur, about 140 miles above Allahabad, according to the same authority the river was 'plied with much activity, the reach of the river at that Military station having the appearance of a port on a small scale'. Similarly, there was considerable boat traffic on almost all the rivers of the Punjab. Indus was navigable up to Dera Ismail Khan, 800 miles inland. On the

western coast rivers like Narbada and Tapti were used by boats of all sizes but to only small distances inland. In the eastern part of the country, owing to difficulty of constructing roads, the main channel of communication was the wonderful waterways with which Nature had endowed the country. In the South also, there was considerable boat traffic in the Godavari, Kistna and Cauvery deltas.

The decline began with the construction of the railways in 1855. In the beginning the construction of the main line acted as a stimulus to the river traffic as a feeder to the railway. Construction of branch lines, however, deprived the rivers of this rôle. Bulk of river transport was handled by country boats, which depending as they did for their movement on the velocity and direction of wind and water were slow. They were not organized, and therefore, were not able to give the security and safety which were offered by railways. Consequently, both goods and passenger traffic began to be diverted to the railways in larger and larger proportions.

At about the same time big irrigation projects were planned and executed, which resulted in withdrawal of large quantities of water from the rather meagre winter supplies of the rivers, making navigation conditions in the upper reaches difficult. In the first few projects arrangements such as locks in the weirs and at canal falls were provided for navigation in the irrigation channels. But very restricted use was made of the alternative. Probably because, whereas navigation through the river was free, the use of canals entailed payment of tolls. Besides, most of the important places previously served were situated on the rivers while the canals passed through rural areas. As extension of railways progressed side by side, no attention was paid to training the depleted rivers to afford navigational depths. In the deltaic portions, where railways were difficult to construct and navigation was the only means of transport, some conservancy measures continue to be taken even now.

In Europe, on the other hand, in spite of the fact that railway communications existed and were being extended as in India, great works for improvement of inland navigation were undertaken. Between 1875 and 1900, German Government executed a programme of river improvement and artificial waterway construction at an enormous expenditure of nearly Rs. 66 crores. The Rhine, in which only small vessels of very shallow draft could navigate as far as Strausbourg, was converted into a deep channel capable of taking barges of as much as 9' draft as far as Cologne, while vessels of over 600 tons capacity could now go as far as Strausbourg. The increase in traffic as a consequence of this work was tremendous. Between 1882 and 1902 the inland German fleet was trebled to cope with the increased traffic. Amount of coal transported from Dortmund rose from a little over 12½ million tons in 1870 to 60 million tons in 1900. It is of interest to note that the region was also served by a very efficient and a fairly cheap railway system. As a matter of fact, it is said that the railway system in the locality was about the cheapest in the whole of Europe. It is due to the existence of German waterways that German industries flourished as they did before the war. France, Belgium and Holland also developed their waterways in the wake of the German effort. Russians, after the first World War, planned to link up the White Caspian, Azov and Black Seas by a continuous waterway capable of taking 10,000-ton ships as far as Moscow from the Black Sea and 10,000-ton barges carrying oil from the Upper Volga to Leningrad.

Water transport is generally much more economical than any other means of transport. Although slow, lack of speed is more than made up by the great bulks that can be handled at a time with suitable craft. Weight for weight fewer men are required to man the cargo. Capital cost of equipment and maintenance and construction of necessary works are, if anything, cheaper than the railway system. In the western countries the freight charges are generally $\frac{1}{2}$ to $\frac{1}{3}$ the charges by rail. Water transport, therefore, should have suited better a poor agricultural country like India where speed was not an important factor. But political reasons outweighed economical reasons, and while the State helped extension of railways

by guaranteeing minimum profits and extending other facilities, inland navigation was left severely alone to fend for itself. Due to this neglect inland navigation is practically dead in all parts where road and railway network has spread. In riparian areas country boats still carry local traffic over short distances along the channels.

Steam vessels have never been used extensively on the waterways of the country. Their use was mainly confined to the eastern parts comprising Assam, Bengal and Bihar. As the operating concerns were practically monopolistic, having no competitors in the field, craft has remained old-fashioned. And, where owing to extraction of water for irrigation the depths of channels became less, the services were withdrawn instead of introducing newer craft suitable for lesser depths. In other countries there has been a progressive improvement in the design of craft and shallower and shallower drafts have been the aim, so that the routes can be extended instead of contracted. The strength of fleet has also remained almost static through all these years. The neglect, therefore, appears to have not only been confined to maintenance of channels but also to improvement of equipment and craft. Due to lack of competition, there was no incentive for the existing transport organizations to improve craft. The State did not think it worth while to interfere either. So much so that even today naval architecture does not figure as a subject of study in the curricula of the country's various Engineering Institutions! During his inspection of the few workshops that exist in Calcutta for construction of flats, Mr. Otto Popper, a Navigation Expert of Economic Commission on Asia and the Far East, recently invited to India, remarked that the designs of some of the craft being built were antiquated and extravagant.

Partition of the country has had further unfortunate effect on inland navigation. The Eastern States of the United India have been so cut up that Assam has now no direct water link with West Bengal, and West Bengal has lost her connection with the neighbouring States of Bihar and Uttar Pradesh. Inter-communication between these means passage through nearly 400 miles of Eastern Pakistan. Although both countries are signatories to the Barcelona Convention, which provides for free passage of traffic from one country to the other, recently passage of goods from Assam to West Bengal became not only difficult but almost impossible. Jute and tea dispatched from there were held up in Pakistan affecting the industries in West Bengal and India very adversely.

Another adverse effect of the partition has been the gradual withdrawal of the operating fleet to Eastern Pakistan. No blame can be attached to the operating companies, as Eastern Pakistan offers a compact unit for operations. While in Indian waters due first to trade barriers between the two countries and secondly inter-State restrictions on movement of goods within the country itself, operations become both vexatious and uneconomical.

During the last war, when the operation theatre was near the borders of the country and transportation of supplies in much larger bulks than had ever been known before had to be effected from one part to the other, it came out that the railway and road system which had been built up, and were considered to be sufficient, were hopelessly inadequate. Frantic efforts to make use of the existing waterways with patched up equipment were made but proved unsatisfactory.

Both, therefore, for economical and strategical reasons, it is absolutely necessary not only to rehabilitate navigation but also to extend it as far as possible. The case of Europe has already been referred to. Improvement of navigational channels brought in its train industrialization of regions, which in turn brought economic prosperity. Same has been the experience in the United States of America and other progressive countries. In the United States, longer and newer channels are available for navigation and improvement in the design of towing vessels and barges has been phenomenal. Freights weighing as much as 23,000 tons are being transported in one tow. It is evident, therefore, that in the interests of national economy inland navigation must be improved. It will be a mistake to wait for traffic being

available before any improvements are carried out. As has been stated, experience in other countries has been that great industries get set up along navigable waterways and water-borne traffic grows to tremendous volumes.

Improvement of inland navigation need not be in competition with the railway and road transport. Both railway and road transport have been nationalized. Water transport can, therefore, be organized in co-ordination with these other means of transport. It should be possible to bring in existence, points of contact between road, rail and water transport and facilitate transshipments. Mr. S. A. Thompson, in an article in the *Engineering Magazine* of July 1902, quotes French official circles saying, 'It is conceded that waterways and railways are destined not to supplant but to supplement each other. Between the two there is a natural division of traffic. To the railroad goes the least burdensome traffic, which demands regularity and quick transit: to the waterways gravitate the heavy freights of small value, which can only be transported when freights are low.... Waterways, by increasing traffic, are rather the auxiliaries than the competitors of railroads. In procuring for manufacture cheap transportation for coal and raw materials, they create freights whose subsequent transportation gives profits to the railroads.'

There are two aspects of navigation which need attention in this country. The existing channels have to be improved and newer routes opened up in order to reach more inland localities. The second is the operational side. As has been said before only organized operators owning vessels and flats exist in West Bengal and Assam. There also their activities are shrinking. Indian enterprise has not taken much initiative in the matter of organizing navigation concerns. Foreign capital is also not likely to find conditions of operation attractive. In the circumstances organization will have to be State-owned or State-aided.

Mr. Otto Popper recommended a start being made with organizing the country boats that still exist in waterways like that of the Ganga into co-operative units which would offer security and safety to the consignments sent through them. In order to ensure these, as well as effect speed in deliveries and better turn rounds, he recommended the use of tugs for towing fleets of boats. He calculated that organized in this fashion, the freight costs would be in the neighbourhood of three-fourths of an anna per ton-mile. The railway freights, at present, are in the neighbourhood of two annas per ton-mile. The organization could be handled by the existing railway managements. Gradually the country boats would be replaced by modern barges.

Improvement of waterways entails river conservancy works to train deep channels during season of low water. This should be a comparatively cheap proposition. On the Ganga the annual costs would not be more than Rs.300 per mile, including dredging of difficult shoals up to Allahabad. The upper reaches and newer channels will require in addition, more water being made available during dry season. This can only be supplied if it could be stored during the monsoon months when the supplies are copious.

For the single purpose of improvement for navigation this would be expensive even if organized traffic were making use of the waterways. When traffic has to be organized from a scratch the projects would be very much more expensive. They can only be undertaken economically on multi-purpose basis, which would enable the necessary works being utilized for other uses such as flood control, irrigation and power generation. In the Tennessee Valley, which is the most recent development of this type, it has been estimated that projected for the single purpose of improving the 630 miles long channel for navigation would have cost about \$ 225 million, whereas the allocated cost for navigation from the multi-purpose system of flood control, navigation and power generation is in the neighbourhood of \$152 million—less than 70% of the single-purpose project. Wherever possible, therefore, the country's navigation projects must be planned on multi-purpose basis.

The potential of extension of navigation waterways is great. Investigations have shown that it is technically feasible to connect up the western and eastern

coasts through multi-purpose works on the Narbada, Rihand, Sone and the Ganga. A number of dams, weirs and locks will have to be constructed. Other principal features of development will be flood control in the lower reaches of the rivers, extension of irrigation to millions of acres and generation of huge blocks of power. Similarly, the Tista can be utilized to provide an all-India waterway connection between Assam and West Bengal, in addition to generating useful blocks of power and making water available for irrigation in north-west Bihar, northern part of West Bengal and the south-western part of Assam. These projects will necessarily be very costly although self-financing and will take a long time to execute. The development will have to be gradual in consonance with the availability of finances, men and materials.

Important projects in hand at present are the Damodar Valley Project in Bihar and West Bengal. As at present planned, the project will provide for a navigation channel connecting the lower Raniganj Coalfields with the Hooghly. A suggestion was made to the Corporation to investigate the feasibility of extending the navigational feature further upstream in order to link up Jharia Coalfields with Calcutta. At present the Corporation's view is that such an extension would be uneconomical. It would be desirable, however, for them to keep future development in view. With the execution of the first phase of the project, the region is likely to be more industrialized than it is at present. Facility of water transport will not only reduce the likely congestion on the existing railway system but would, as has happened in the region of Rhine, lead to greater industrial development. Planners would, therefore, certainly provide for suitable locks in the lowermost dams. Hirakud Project has a distinct navigational feature. It envisages making the river below the Hirakud Dam navigable by suitable works. There will be provision for extending the facilities to the top-end of the reservoir by providing locks both in the subsidiary and the main dams. Kakrapar Project in Bombay, similarly provides for navigational facilities being available from the sea face near Surat right up to the reservoir at Kakrapar about 50 miles inland. The last important navigation project under investigation at present is the Ganga Barrage Project. This will provide for a canal taking off the barrage to be constructed across the river having its outfall into the Bhagirathi establishing an all-India navigation route from the Bay of Bengal to the hinterland of Bihar and Uttar Pradesh. This last project has immense economic potentialities. Besides establishing a direct link between the Port of Calcutta and the great cities of Bihar and Uttar Pradesh, it will connect up the mineral-rich Damodar Valley with a large part of the country through water route.

IRRIGATION

By SARDAR MAN SINGH, I.S.E., Member, Central Waterpower, Irrigation and Navigation Commission, New Delhi.

(Communicated by Dr. S. L. Hora, F.N.I.)

SUMMARY

Nearly 70% of India's population of about 300 millions is occupied in agriculture and allied avocations. India has an area of about 779 million acres of which 380 millions are cultivable. No amount of industrial development is likely to change the economic character of the country which must remain essentially agricultural.

In spite of a vast area being under actual cultivation, the country is deficit in foodgrains and such essential agricultural products as jute and cotton. These deficits have had to be made up by importing the commodities from foreign countries. Colossal amounts have been spent every year to do this. This state of affairs affects her economy adversely. All out efforts are now underway to stop the unproductive drain on her resources. As a result it is expected that the import of foodgrains will be stopped by 1951.

The population of the country is growing at a fairly fast rate. In order, therefore, to catch up with the consequent increasing requirements of food, long-range solutions have to be aimed at.

A study of the agricultural statistics of the country reveals that her yields of various crops from the cultivated land are the poorest in the whole world. The most important reason for this is the lack of irrigation facilities to the major part of the cultivated area. This country has a very precarious rainfall, and unless water requirements of the various crops are made up by artificial means, frequent partial and total failures occur. Crop-cutting experiments in the various States have shown that introduction of irrigation increases the yields of various crops from 30 to 150%. It is, therefore, obvious that provision of irrigation facilities to even a small percentage of the total area would make the country self-sufficient in food as well as other agricultural commodities.

The country at present irrigates nearly 47 million acres of the cultivated land. Although this is the largest area in the whole world, it constitutes only about 18% of the total cultivated area. Of the surface water resources only about 6% are being utilized for the purpose. The scope for extension, therefore, is tremendous.

Hitherto, mostly surface run-off has been utilized for the purpose of irrigation. A very small quantity from underground resources is also drawn. Exploitation of this source must continue to be small as this method of irrigation is more expensive. In utilizing the surface resources diversion from flow of streams into a network of canals by construction of weirs and barrages across the streams has been the method most in vogue. In the south reservoirs of varying sizes have also been created behind dams constructed across natural streams. Owing to inequality of distribution of rainfall over the year (generally 90% of the total annual precipitates during the monsoon months of mid-June to mid-October) recourse has to be taken to schemes of impounding the excess water in reservoirs and utilizing it during the leaner periods. Works designed on this basis are generally very much more expensive unless the costs can be distributed over other features which can be incorporated in such works. In other words, the most economical way of planning for irrigation is to design the future works for the multi-purposes of flood control, generation of power and extension of navigation. Such works, unlike the existing irrigation works, which cater for seasonal irrigation only, will make water available all the year round enabling at least two crops being grown in most of the commanded areas. The yields will thus go up by at least 150 to 200%.

Some of the important projects under execution in the country are Bhakra-Nangal in the Punjab, Damodar in Bihar and Bengal, Morin Bengal, Hirakud in Orissa, Tungabhadra in Madras and Kakrapar in Bombay. These between them will provide perennial irrigation for nearly 8 million acres and will help to provide about 3 million tons of additional foodgrains and large quantities of cotton and jute.

In order, therefore, to rehabilitate and put the economy of the country on a sound basis, it is most essential to give the highest priority to such works in the Development Plans of the country.

With the attainment of freedom we have to retrieve from our position of dependence on others for manufactured goods of almost all kinds. From mere

producers and exporters of raw materials we have to turn into manufacturers of at least such of the items for which raw materials are available in the country. There is a tremendous gap to fill, and sustained effort is necessary to achieve the objective. But policies are being shaped to that end. However, whatever degree of industrialization we might achieve, the economic character of our country must remain essentially agricultural. We have a population of nearly 350 million souls to feed. Of our total area of about 779 million acres an area of 380 million acres is cultivable land. Naturally a large proportion of the population must continue to apply itself to the task of cultivating the land and allied activities.

Of the total cultivable area only 293 million acres is under actual cultivation. Of this 50 million remains current fallow. Our production of foodgrains is in the neighbourhood of 40 million tons a year. This is short of our requirement and since 1943 we have been partially making up the deficit by importing foodgrains from foreign countries. The maximum quantity imported was during the last year, that is 1949, and it amounted to nearly 3.5 million tons. Although huge, this quantity was short of our requirement. However, even inadequate imports have been costing us over 100 crores of rupees annually. Recurring expenditure of this colossal sum is an unproductive drain on our resources and tends to upset the economy of the country. All out efforts to minimize this drain and stop it altogether by 1951 are, therefore, being made now.

Another disturbing factor of recent occurrence is the precarious position of supplies of jute and cotton from our neighbour Pakistan. As long as our relations with her remain unsatisfactory, it will be difficult to rely on adequate supplies from that country. In addition to self-sufficiency in food, therefore, we have also to grow more jute and cotton.

Short-term expedients to achieve the objective include bringing under cultivation more area and extending irrigation to as large areas as possible. For this last purpose, easily and speedily constructed works, such as tube and open wells, diversion of supplies from small streams, construction of small reservoirs and extension of irrigation from existing sources have been undertaken and are being pushed through. During the last seven years, nearly one million acres more of land has been reclaimed for cultivation and a million and half acres of additional land has had irrigation facilities provided for it. More areas are being put under jute and cotton as well. These efforts and effective check on hoarding, which is also to a small extent responsible for the shortage, are likely to yield satisfactory results for the time being.

But these measures are not calculated to provide for the growth of population of the country. The annual rate of increase is estimated at four millions. In order to catch up with consequent increasing requirements long-range solutions become inevitable.

In the study of agricultural statistics of the country, one thing that strikes one the most is the extremely poor yields that we get from our lands. In fact our yields are the lowest in the whole world. What is worse still is that they have been steadily decreasing during the last many years. We produce only 636 lbs. of wheat per acre on average against a maximum average of over 2,000 lbs. in Germany. Our average yields of rice is 829 lbs. per acre against a maximum average of nearly 4,000 lbs. in Italy, while our cotton yield is only 89 lbs. against 535 lbs. in Egypt. The average yields of some of the principal agricultural countries of the world for these crops are 1,100 lbs. for wheat, 2,300 lbs. of rice and 225 lbs. of cotton.

Reasons for this unsatisfactory state of affairs are many. Among the principal ones are—first, general uneconomic holding of the cultivator. This prevents employment of the latest, and more scientific and labour-saving method of cultivation. It is a consequence of faulty systems of tenure and succession. Secondly, lack of sufficient quantities of heavy-yielding varieties of seed for some crops. Thirdly, decrease in fertility of land. This is a result of prevalent unscientific land uses and

methods of cultivation, soil erosion and insufficient use and in some cases lack of use of fertilizers to rejuvenate the soil and lastly lack of facilities for irrigation to the major part of the cultivated area.

The first three reasons are important enough, and if remedial measures could be adopted, they would help in increasing the yields considerably. Dr. Burns estimates that in the case of rice, the yields can be increased by at least 30%, 5% by using improved varieties, 20% by increasing use of manures and 5% by protecting the plants from pests and diseases. It is not difficult to increase the outturn by even 50% if improved methods of cultivation and co-operative farming enabling larger units being dealt with could be introduced. These would involve land tenure reforms and other measures designed to abolish uneconomic holdings. Results in the case of other crops would be equally satisfactory.

But the most important of all reasons which affects the yields adversely is the lack of facilities for irrigation to the cultivated area. Crops require specific quantities of water for their growth and maturity and at more or less specific periods of their life cycle. Nature supplies this by means of rainfall. But in India, more than in any other country, the quantities that precipitate vary very frequently. In his paper on 'Liability of draughts in India, as compared with other countries', G. D. Walker says, 'No country has a rainfall as precarious as India'. North-western part of the country and desert of Rajasthan are practically rainless. In these parts cultivation without artificial application of water or irrigation is impossible. In Deccan districts rainfall is exceedingly precarious. Owing to the great irregularity of rainfall and the long intervals during which crops may be exposed to heat of the sun and dry winds there may be a complete failure of crops. A succession of two or three such seasons brings along severe famines. In areas of moderate rainfalls, maldistribution over the rainy season results in partial or complete failure of crops. Irrigation thus is a necessity in most parts of the country except in such parts as Assam, Western Ghats, etc., where rainfall is both copious and adequately distributed over the crop season.

No overall reliable crop-cutting data is available to show the difference that irrigation makes in the yields of various crops. But the following figures collected from the 'Report of Marketing of rice in India and Burma—1941' make an interesting reading. These figures were results of actual crop-cutting experiments conducted in the States mentioned.

Average outturn of paddy

States			Irrigated Lbs. per acre	Unirrigated Lbs. per acre
Madras	..	..	1,694	1,138
C.P. and Berar or Madhya Pradesh	..	..	1,200	900
U.P.	..	..	1,100	850
Punjab	..	..	1,269	587

Average outturn of wheat

States			Irrigated Lbs. per acre	Unirrigated Lbs. per acre
Punjab	..	..	967	572
U.P.	..	..	1,200	800
Bombay	..	..	1,250	510

In the case of paddy the increase in yield varies from over 30% to 100%, while in the case of wheat the percentage varies from nearly 50% to 150%. Cotton, jute and sugarcane also give similar results.

Irrigation, therefore, becomes the foremost desideratum for remedying the poor yields and making the country really self-sufficient with regard to her requirements of food and other agricultural products, and its extension to as large an area as possible becomes a matter of vital necessity. Otherwise too, unless water for irrigation were made available, efforts to remedy the other causes would not be of much avail.

In order to assess the extent to which irrigation can be extended, it is necessary to review the present conditions and to estimate the quantities of water available for the purpose. Of the total cultivated area of 293 million acres, about 47 million are irrigated. This, though the largest area in the world, is only about 16% of the total cultivated area, so that if water were available, there should be large scope for extension.

The country depends for its water supply for irrigation mainly on two sources—rainfall and the underground reservoirs of water. Glaciers and snow-clad portions of the Himalayas also contribute fairly large quantities. No estimates of the underground resources have yet been attempted. But where water exists at reasonable depths, and other means of irrigation are lacking or are difficult due to unsuitable terrain, it has been made use of for the purpose. It is drawn from open and tube wells by various methods. Cost of irrigation from underground sources is, however, generally high. But on account of the small outlay on individual works and the speed with which results can be obtained, utilization of this source has great economic value and fairly extensive use of it has been made in the past. Over 20% of the irrigated area is served from this source at present.

The total annual average precipitation of rainfall in the country is about 40". Of this about 50% is lost in evaporation, transpiration and absorption. The rest 20" amounting to nearly 1,300 million acre-feet drains off as surface flow through the great rivers of the country. Of this surface flow an extremely small proportion amounting to only about 5% is being utilized at present for irrigation. Water also, therefore, is available in immense quantities for use for extension of irrigation to the rest of the cultivated area. As a matter of fact, it is more than enough to provide perennial irrigation for the entire cultivated land.

The problem of utilization, however, is complicated by the maldistribution of rainfall, both in respect of areas and time. Variations over the different parts of the country have already been referred to. As regards variation over the time, nearly 90% of the annual precipitation occurs during the main south-west monsoon months of mid-June to mid-October. During this period rivers overflow their banks, very often causing serious damage to life and property including at times utter ruin of crops in the flooded countryside. During the rest of the year the discharges are low and in a large number of cases drop down to almost nothing in the driest part of the year. For this reason the scope for use of the immense surface flow becomes rather restricted.

There are a variety of ways in which surface flow is utilized for irrigation. The works according to the Irrigation Commission of 1901 'include works of many varieties and magnitudes ranging from the rude contrivances which enable the cultivator by swinging a basket to raise water from a pond, to the huge embankment of earth or masonry holding behind it a lake of many square miles, or from the small temporary well, a mere hole in the ground lined with brushwood to the great canal which, carrying for some hundreds of miles a volume of water equal to that of a large-sized river, delivers into a network of smaller channels for the irrigation of over a million of acres'. Most economical works have been those in which flow of streams has been diverted into canals running at high levels commanding the area to be irrigated by gravity flow. Such works, especially in the arid north-west part of the country, where they have cost from Rs. 25 to Rs. 100 per acre of area irrigated, have brought back rich dividends in the form of water rates and land revenue. Annual returns in case of some of the works have been as high as 25% of the capital cost. Possibilities of extension of irrigation of this variety have almost been exhausted during

the last hundred years or so. For further extension recourse has now to be taken more and more to storing water during the period when it is copious for use during leaner periods. Accordingly, schemes envisaging storing large quantities of water during monsoons and making use of it during that and the dry parts of the year are being planned. In the south, in addition to command of land from diversion works, some storage works have also been constructed in the past. From these reservoirs network of canals and distributaries take off just as in the case of diversion works. Such works are generally very much more expensive as, besides the distribution system which would be common, the weirs or the barrages have to be replaced by or constructed in addition to the massive structures of dams with reservoirs behind them extending to and submerging large areas of land. Capital costs in pre-war times of such works have ranged from Rs. 200 to Rs. 500 per acre irrigated. Returns from water rates, etc., have just covered the interest and maintenance charges in some cases while in others capital costs have been sought to be reduced by collection of betterment levies from owners of lands benefited. With the current high prices of materials and labour, costs will be two to three times the pre-war figures and, therefore, in some cases works would be uneconomic, if direct returns alone were considered which till recently was the only criterion for adjudging the financial feasibility of works.

Storage works, however, in addition to enabling extension of irrigation, can be utilized for moderating floods which devastate property and crops. By regulating discharges and making adequate flows run over longer period in the channels than the normal, navigation facilities can be planned in addition which will offer more economical transport of materials. Large blocks of electric power can also be generated by passing the releases through penstocks and turbines. Designed for such multi-purposes, the overall costs of works though heavy become very economical. Incidence on irrigation and other features can be reduced to almost pre-war figures.

About a year ago when all the States were feverishly planning for multi-purpose projects, data were collected and it was found that 38 large-sized projects including the projects being sponsored by the Centre if executed would bring under perennial irrigation about 25.3 million acres of additional land. This was, by no means, an exhaustive survey. The potential is really much greater. Owing, however, to the present financial stringency and lack of adequate resources in men and materials to enable a large number of projects being proceeded with simultaneously, it has been decided to concentrate and complete as rapidly as possible about a dozen projects which will provide perennial irrigation for nearly 8.5 million acres. They will be completed in the next four or five years and enable producing nearly four million tons of additional foodgrains besides large quantities of jute and cotton. The principal among these are the Bhakra Nangal Project in the Punjab which will irrigate over 3.5 million acres, Damodar Valley Project in Bihar and West Bengal with an estimated command of nearly one million acres, Mor in West Bengal designed to irrigate nearly 600,000 acres, Hirakud Dam Project in Orissa to irrigate 1.1 million acres, Kakrapar in Bombay for nearly 800,000 acres and Tungabhadra in Madras and Hyderabad commanding nearly another 700,000 acres.

Each acre of land provided with perennial irrigation is capable of yielding additional harvests worth about Rs. 150 every year at the present-day prices. Purely from economic point of view it would be more than justifiable, therefore, to construct works the capital cost of which would work out to even Rs. 2,000 or more per acre. In the State of Mysore, works costing nearly Rs. 1,000 per acre have been planned and undertaken. But as a major share of the increased yield is retained by the cultivator the direct returns usually do not amount to more than Rs. 8 to Rs. 10 per acre in the shape of water rates. There has in the past, therefore, been great hesitancy in sanctioning works estimated to cost more than Rs. 200 to Rs. 250 per acre. Now fortunately there is a better economic appreciation of such works and indirect returns from the consequent general prosperity of the

cultivator are also taken into account. Even so, capital cost of most of the multi-purpose works in progress in the country at present will not be more than Rs. 200 to Rs. 300 per acre. In several cases, they will be as low as Rs. 100. They will, therefore, be self-financing even from the antiquated financial standards. The case of extension of irrigation through such multi-purpose projects to as large an area as possible and, within as short a time as the material and technical resources of the country will permit, becomes irresistible if we have to forge ahead with the material and economic development of the country.

A PATTERN OF LAND-USE PLANNING IN THE DRY AREAS OF THE BOMBAY STATE¹

By J. K. BASU, *M.Sc., Ph.D., F.N.I.*²

and

N. B. PURANIK, *B.A., M.Sc.*

SUMMARY

The problem of maintenance of the productive capacity of the land on a permanent basis requires efficient utilization of the lands according to their use-capabilities. The Land-Use classes should indicate the maximum intensity of use that a land can be put to in a permanent system of farm management. The Land-Use practices suitable for the tract are to be founded on scientific principles and developed in accordance with a physical inventory of the existing state of the agricultural lands and their present use. There is thus a need for a field survey of the tract to ascertain the fundamental factors involved in the Land-Use capability classification. The paper sets forth a procedure—broad in scope—for making a soil conservation survey of the dry areas of the Bombay-Deccan for mapping major physical land features most essential for the development of a soil conservation programme.

A reconnaissance survey of agricultural lands, covering an area of about 80,000 acres on self-contained catchment basis, has been completed in 43 centres scattered over the Deccan and Karnatak districts of the Bombay State. The Saurashtra tract extends over 8 million acres, distributed over seven districts where the rainfall is scanty, ill-distributed but extremely erosive at times. The survey results reveal that nearly 70 per cent is in a more or less eroded condition of which 40 to 55 per cent is in a very highly eroded stage. The good land is mainly flat with a slope ranging from level to 1 per cent. The eroded land on the other hand has slopes between 1 to 2 per cent. Wherever the land has a slope greater than 2.5 to 3 per cent there are barren lands from where soil has been completely washed down in most cases.

With the available data on physical features and allied factors, an attempt has been made to specify a general Land-Use Planning on catchment basis. On this general background more intensive Land-Use Planning can be effected if the details of the physico-chemical make-ups including deficiencies in plant food ingredients are mapped out from farm to farm and recommendations based on agronomic trials conducted at the research stations are adopted for stepping up crop-production on a permanently higher level.

INTRODUCTION

The problem of permanent maintenance of the productive capacity of the land for agricultural use, implies efficient use of the land as a step of first importance. The land-classification relates to the groups of lands according to their suitability to raise certain crops. The object of the planning generally governs the nature of land classification where no general principles could be laid down. The land-use plan designed to bring maximum benefit of the agricultural and forest resources of the region must be primarily based on maintaining the level of productivity from the long range point of view of land utilization. Land-Use Capability Classes broadly indicate the maximum intensity of use that can be practised safely in a long term system of farm management. They indicate how it is practicable to expect increased production by certain intensive practices, as also, how certain lands in any emergency can be put under crops. They also show how to utilize non-cultivable area to get products required for animal world.

¹ The article is based on part of the research data accumulated during the period 1945-50 in the Land Improvement Research Scheme, Sholapur, sanctioned under the five-year programme of the post-war reconstruction schemes.

² Soil Physicist to Government, Bombay State, Poona and Research Assistant, Land Improvement Research Scheme, Sholapur.

Soil and moisture conservation of the land requires not only a correct land-use but also adoption of suitable soil moisture conservation practices to each type of land. This is particularly true, in the scarcity tracts where vagaries of monsoons are well pronounced. The land-use and soil conservation practices though controlled by several factors are to be founded on scientific principles and developed in accordance with a physical inventory of the existing state of the agricultural lands and their present use. There is thus a need for a field survey of the tract to ascertain the fundamental factors involved in the Land-Use Capability Classification and consequent land-use planning. The assessment of each class as to its suitability for different uses contemplated in a land-use planning will however be governed by a detailed study of each small unit in a catchment.

The paper sets forth a procedure—broad in scope—for making a soil conservation survey of the dry tract of Bombay-Deccan for mapping major physical land features, most essential for the development of soil conservation programme of a tract or a region. Further, it would also be useful in the interpretation of data so obtained in terms of Land-Use planning in relation to soil types, slope, state of erosion, rainfall and present land-use. The experience of the cultivators particularly for present land-use could also be fully taken into account in recommending practices which would result in its productive use without deterioration for a long period of time. It has been realized in recent times that agricultural problems should be considered in terms of the smallest unit of study, viz. a catchment. The Soil Conservation practices can be effective, economical and convenient to handle, only if undertaken on catchment basis. Of the two types of survey, viz. reconnaissance and detailed survey of agricultural land, covering an area of about 80,000 acres on individual self-contained catchment, basis, has been completed in 43 centres scattered over the Deccan and Karnatak districts of the Bombay State.

A PROGRAMME OF SOIL CONSERVATION SURVEY

Soil Conservation Survey is a field inventory of the physical features of the land and its environmental factors required for a proper programme of soil moisture conservation. The efficient Land-Use and soil conservation practices necessary for the tract, though controlled by several factors must be developed in accordance with a physical inventory, particularly of soil-slope conditions, nature and degree of past erosion, rainfall, its distribution and present land-use.

In view of its importance a programme of reconnaissance survey was carried out in the scarcity tract during the last five years (1945-50) with the object of obtaining data regarding—

- (1) the various soil types, their depth, colour, surface conditions and environmental factors such as gradients, rainfall and its distribution,
- (2) the extent of damage already done by erosion in several parts of the scarcity tract as also the nature of such damage, and
- (3) the physical and chemical properties of soils particularly as affected by soil erosion in the past.

In view of the very vast area of the tract it was decided to choose only a few centres suitably broadcast over the region for carrying out the actual fieldwork. At each centre, a few self-contained catchments each totalling up to about 2,000 acres in extent were selected by random for making a detailed study. Information about—

- (1) Surface conditions, woods, cracks and other surface features,
- (2) Crops, their normal yields, and their extent in area,
- (3) Soils, their depth and colour, gradient and state of past erosion, etc.,

in each of the catchments chosen for study, was collected both by fieldwork and from revenue records of the village. Suitable surface soil samples were drawn from

each type of soil met with down a slope-line running through different soil types. At each sampling spot, soil and surface conditions were carefully examined.

Soil, types, occurrence, gradients and their inter-relationships

Types.—The scarcity tract extends over 8 million acres and is distributed in the seven districts of the Deccan and Karnatak regions of the Bombay State. The rainfall in this tract is scanty (below 25"), ill-distributed and erosive in character with frequent occurrences of famine conditions. For purposes of description and convenience the scarcity area is divided into two circles: North and South. The former consists of the districts of Ahmednagar, Sholapur and eastern portions of Poona and Satara and the latter includes the districts of Bijapur and eastern part of Dharwar and Belgaum in the Bombay State. The soils of the South Circle as a class are very deep as compared to those of North Circle. The classification and nomenclature of these soils as described by Dr. N. V. Kanitkar¹ are maintained and are used as follows:—

North Circle.—Based on soil depth. Deep (above 18"); Medium (9" to 18"); Light shallow (below 9").

South Circle.—Based on soil colour. Deep Black, Medium Black, Limy or Kankar.

It may be noted that these different types are but the results of the same factor, viz., soil erosion. Hence the above types can be brought together on the common basis of the degree of past erosion into—

- (1) The uneroded or slightly eroded soils, corresponding to deep and deep black soils,
- (2) The moderately eroded soils, corresponding to medium and medium black soils,
- (3) The highly eroded soils, corresponding to light and limy soils.

Soils under (1) are usually deep black in colour and sufficiently deep to stand a good crop, while those under (2) and (3) are shallow and poor—particularly in the North Circle.

Occurrence.—The land has been exposed to ravages of soil erosion all along in the past without any kind of planned protection on scientific basis. Usually, it is observed that all the three soil-types exist in a catchment except where erosion has been too little or too severe so as to wash out one or more types completely. Slightly eroded soils in general are found on the ridges of a catchment whereas the moderately and highly eroded types may exist either in the middle or lower reaches of the catchment according to the severity of erosion. The sequence down the slope is the reflection of the process going on unhindered over ages.

Slopes.—It is very difficult to say whether the slope of the land is the effect of continued erosion or different degrees of erosion are due to the original slopes of the land. It is found that good land is mainly flat with a slope ranging from level to one per cent and it usually occurs on the table-lands of the ridges of catchments. The eroded land, on the other hand, has slopes ranging from 1.25 to 2%. Wherever the land has a slope greater than 2.5% there are barren lands from where the soil has been washed down due to erosion of accelerated type. It is also found that the more eroded types have greater slopes which in turn are conducive to still greater erosion.

Soil Erosion, its extent and nature of damage

During the last five years an area over 80,000 acres in 43 centres suitably broadcast over the entire scarcity region was surveyed and the extent of each type of

¹ Dry Farming in India, Scientific Monograph No. 15, I.C.A.R.

soil in these centres was studied. The summary of results is shown in the following table:—

Name of the circle	No. of centres	Uneroded soils or slightly eroded	Moderately eroded soils	Highly eroded soils	Accumulated soils	Total
North	22	6,862	12,236	15,324	5,811	40,233
South	21	7,956	18,916	10,641	2,795	40,308
Total	43	14,818	31,152	25,965	8,606	80,541

The above areas expressed as percentages work out as follows:—

North	22	17	31	38	14	
South	21	20	47	26	7	
	43	18	39	32	11	

If the above area is enough to yield a fair estimate of the conditions in the scarcity tract, it is found that only 17% and 20% of the total area in the North and South Circles respectively, are now left in the slightly eroded condition, whereas vast areas amounting to 69% and 73% of the total area have been eroded more or less severely. Of the eroded areas, in the North Circle especially 56% is now left with a soil depth less than 9 inches.

An extreme situation is met with at six places in the North Circle where not an acre of original deep soil (uneroded) is left. Even on the ridges where we should usually have deep soils, there are no stocks of soil which we can afford to loose, while lower down on the slope the position is worst.

This fact clearly brings out the havoc brought by soil erosion to our soils and the gravity of the existing situation, emphasizing both the need and urgency of suitable anti-erosion measures on catchment basis carried out on the scientific lines.

Soil Types and Soil Properties

During the survey suitable soil samples were drawn along lines sloping from ridge to the valley and running through different soil types. Three to 6 spots of sampling equi-distant from one another were chosen in each of the soil types met with, along a few such lines. These samples were analyzed for their humus, calcium carbonate, clay, silt and exchangeable calcium contents. The table (p. 485) shows the results of the analysis.

1. The increase in lime contents of soils in eroded areas indicate that the surface layer constituents being easily washed away expose the sub-surface layers containing higher lime contents, which are leached down the profile in the normal process.

2. In the South Circle, clay content of the soils as a whole is satisfactory. But, this vital constituent which influences major soil phenomena is found to be deficient in the North Circle where the soils are comparatively shallow. This dual loss severely curtails the field-carrying capacity of these soils for moisture and fertility factors. The colloidal complex containing exchangeable bases being associated with fine clay particles also shows a similar behaviour as clay itself.

Property	Uneroded		Moderately eroded		Highly eroded	
	South Circle	North Circle	South Circle	North Circle	South Circle	North Circle
Humus % ..	0.52	0.89	0.51	0.96	0.54	0.75
Lime % ..	6.00	9.00	7.00	9.00	9.00	11.00
Clay % ..	62.00	43.00	52.00	43.00	44.00	27.00
Ex. Ca in Mg equivalent % ..	50.00	50.00	43.00	49.00	44.00	25.00

3. In the South Circle, soil properties appear to undergo perceptible changes even at moderate erosion, whereas in the North Circle the same occurs only at the highly eroded stage.

4. Thus on the basis of soil properties—particularly clay contents—as affected by soil erosion, these soils can be grouped into (1) slightly eroded to moderately eroded and (2) highly eroded types in the North Circle, and (1) uneroded and (2) eroded types in the South Circle. The first type of the former can be sub-divided into two groups (*a*) slightly eroded, (*b*) moderately eroded on the basis of soil depth as affected by soil erosion in the past. In the case of South Circle, the second type can be further divided into (1) moderately eroded and (2) highly eroded stage as revealed by the soil colour and lime surface contents. Thus the original three groups classification of these soils adopted for field study can be well-fitted in the above scheme based on soil properties.

PATTERN OF LAND-USE PLANNING RECOMMENDED

The findings of the various aspects of the soil conservation survey are aimed at obtaining a thorough knowledge of the fundamental aspects of the factors involved in the study of soil erosion and its control. The soil and moisture conservation practices most suitable to the different soil climatic complexes of the tract and the useful effects of these on soils and consequent crop production also require the fundamental knowledge of soils and environmental factors of the land.

A watershed or a self-contained catchment is the smallest unit of study in a reconnaissance survey of a tract. The factors involved in such a study include the following items which affect the entire unit:—

- (1) Rainfall and its distribution,
- (2) Soil-slope conditions,
- (3) General topography,
- (4) State of past erosion,
- (5) Present Land-Use practices.

Information on some of the above points has been consolidated for the dry tract of the Bombay-Deccan in general and the 43-centre of survey work in particular to evolve a general land-use classification for soil-moisture conservation on a catchment unit taking into account the following considerations:—

- (1) Soil Moisture practices needed for erosion control,
- (2) Soil amelioration and soil management required for maintaining soil productivity,
- (3) Crops, their varieties and rotations to be adopted, for obtaining moderate to high yields.

For the cultivable lands in the entire scarcity tract 'Bombay Dry Farming Method' with a schedule of operations has been the basic recommendation and is in actual practice throughout the region.

In a dry tract like the Bombay-Deccan, where the rains are mainly erosive in character and the lands are exposed to ravages of soil erosion, the word 'contour' and 'all agricultural practices along contour' assume a special significance. The contour furrows in tillage operation act as innumerable miniature bunds which obstruct the run-off and erosion and help to localize the phenomena of soil erosion throughout the area. The additional needs on the above lines either singly or in combination are required for developing the individual catchment of the tract for correct Land-Use Planning.

Broadly, the cultivable dry land of the tract can be classified into three categories or classes on the basis of soil-slope conditions or the degree and susceptibility towards erosion according to its suitability for agricultural use as follows:—

- I. Lands (1) either level or nearly so,
(2) slightly affected by erosion ;
- II. Lands (1) gently sloping,
(2) moderately affected by erosion ;
- III. Lands (1) with steep slopes,
(2) severely affected by erosion or susceptible to erosion.

The first of these does not need special practices for successful agriculture but would maintain the general level of productivity with the normal practices of tillage for structure, rotation of crops and normal manuring. In the case of the second class of lands, some simple practices of erosion control and moisture conservation such as contour tillage, contour strip cropping, etc. in addition to normal agricultural practices, would be necessary for maintaining the productivity of the soil. But in the third class, planned practices for the control of erosion and soil-moisture conservation are the basic needs for successful cropping. Contour bunding and contour trenching, gully plugging and strip cropping are the special recommendations specified for this class in addition to the normal agricultural practices in vogue.

This classification by itself is neither complete nor enough for Land-Use Planning and would certainly need the other aspects to be completely investigated and improved upon as further investigations on research farms, are carried out.

In the non-cultivable areas of the catchment a two-group classification of the following type is found to be useful—

- I. Lands (1) highly eroded to barren and sloping,
(2) level but extremely poor for crops ;
- II. Lands (1) very steep slopes, hilly or cut up regions,
(2) severely eroded.

The first of these though too poor for growing crops support usual grasses and should either be left fallow or exposed to only controlled and planned grazing. The root system which is extremely useful to such land is preserved and stands to erosion which in turn promote permanent vegetation useful for the cattle. The latter is extremely hilly where normally nothing would grow. Contour trenching, afforestation and gully plugging are some of the typical practices necessary of such tracts which are to be brought up to forest land in due course of time.

The Land-Use Planning is done on mainly two broad lines, one is extensive involving an entire tract down to a catchment, while the other is intensive and is carried out at closer intervals—say from farm to farm in the individual catchments. The former needs what is known as a reconnaissance survey of the land on catchment units, while the latter requires a detailed survey of the soils in each small unit or survey numbers together with the knowledge of their physical and chemical

properties, deficiencies of plant food and information about the various crops and their varieties which would thrive well in these regions. The detailed land-use capability planning of each farm would have to be carried out on the general background of the pattern detailed above for the catchment unit as a whole. The recommendations of the research stations based on the agronomic, tillage operations, and manurial trials would have to be incorporated in each farm of the catchment, with suitable modifications to adjust to the local features and the present land use, so as to step up crop production on a permanently higher level at the same time maintaining the productive capacity of the soil.

The Land-Use Planning on individual farms is a sort of reorganizing different kinds of lands and determining their most effective use under the prevailing conditions as also after adopting suitable intensive practices. Such a problem in India would be very vast, requiring a huge well-planned organization to tackle it. All the same it is essential that early attempts are made to take up the problem in hand which is so very vitally important for crop production.

SOIL CONSERVATION ENGINEERING

By A. DE VAJDA, Damodar Valley Corporation, Calcutta.

(Communicated by Dr. B. C. Guha, F.N.I.)

SUMMARY

Soil conservation has been practised from the earliest beginnings of civilization, but it is only recently that it has developed to a distinct branch of engineering. Since man-made erosion has been recognized as one of the main causes of increasing floods and desiccation, a change in our attitude to our natural resources from exploitation to conservation becomes imperative.

Rivers should be developed not as short-term profit bringing schemes but for the permanent benefit of the population in full harmony with natural conditions.

Headwaters control is an essential part of almost all river valley schemes, although it may not be possible to control floods entirely without major storage reservoirs. Under conditions prevailing in the Damodar Valley both methods have to be combined. The major dams can store only 50% of the average yearly run-off. The detention and use of water in the uplands will, therefore, be only beneficial to the scheme. Local conservation practices, consisting mainly of paddy terracing and seepage tanks (ahars) are a most valuable asset and should be incorporated in the overall scheme. Conservation engineering will consist mainly of terracing and small detention dams, combined with proper land use, forest managements and irrigation schemes.

These measures will reduce substantially flood peaks and the silting danger for reservoirs designed at present mainly for flood control. When conservation has achieved its objectives, the storage space reserved for floods can be reduced and more storage water used for power and irrigation. This will improve the economic value of the scheme.

Soil conservation measures have been practised from the earliest beginnings of civilization. Its basic principles, as they are established now, were known and applied by the cultivators in China, South-East Asia and all countries situated around the Mediterranean as also in many others. But it was not until very recently—only some 25 to 40 years ago—that Soil Conservation Engineering developed into a distinct branch of engineering, based on specific research and studies.

This late development is probably due to the fact that modern engineering originated in Western Europe, where soil conservation problems did not play a rôle of overall importance in the economic and social life of the people. The favourable climatic conditions and a stable, permanently settled population conduced to the conservation of the soil and water resources.

In spite of frequent wars and internal troubles, the cultivators of Western Europe were firmly settled on the soil, the same family cultivating the same piece of land sometimes for centuries, and making use of the collected experience of their forefathers. This experience, together with the favourable climatic conditions—good distribution of rainfall and snow cover on the hills and in the northern plains,—made it possible to maintain the balance between soil, water and agricultural productivity through the centuries.

It is interesting to note, however, that when the descendants of the same families crossed the seas and settled as colonizers on the American continent and in Africa, their attitude towards the soil changed entirely. As a result of great abundance of land, cutting of forests and a primitive, shifting cultivation replaced the careful methods of their homeland. In America, both in the U.S.A. and on the southern continent, the results were disastrous; the same can be said about South Africa and Australia.

With increase of population in the U.S.A. and with the higher demand on food production and on water for all purposes, the problem of conservation of soil and water in all its aspects—physical, social and economic—suddenly assumed paramount importance. Consequently soil conservation was taken in hand, all its

aspects were studied, the diagnosis established, remedies proposed and tried out, and a great campaign for conservation of natural resources started, everything being done with the characteristic promptness and energy of the American people. And for the first time in history man's influence on his environment was consciously recognized and soil erosion—in contrast to geological erosion—diagnosed as a mainly man-made evil.

The remedies proposed and applied consist, accordingly, in a change of man's attitude to his environment. The basic change is in the field of ethics as well as of economics. Man should not consider his environment—land, forest and rivers—as a source of exploitation for his personal profit, but as wealth entrusted to him by nature for which he is responsible to the generations to come. Soil, water and wild life are renewable natural resources—renewable and capable of being developed if managed and used properly.

Land's productive capacity depends on a large number of factors. Some of them are natural, such as the quality of the soil, climate, hydrological conditions and slopes; while others are human, such as land-management, irrigation, drainage and various agricultural, biological and technical measures. Human activities related to the use of soil and water must be adapted to the existing natural conditions. This being so, the measures for conservation of these resources will differ widely.

To find and to apply the best treatment for every specific area is the main task of conservation. This applies not only to soil conservation and land use proper, but also to river valley schemes wherein the real task is to make the best and full use of water resources. Seen from the conservation viewpoint, river valley projects should always be developed in complete harmony with natural conditions, such as climate, geology, soil, orography, and also with the social and economic conditions of the population.

River valley projects and multiple-purpose use of water resources are not a new phenomenon. There were big, well planned multiple-purpose valley schemes in Mesopotamia, China and Egypt, equalling in magnitude and boldness of conception our present schemes. In more recent times, many such river valley projects were taken up both in Europe and in the U.S.A.; but very often their only aim was to produce wealth in the form of power or crops, regardless of the long-term interest of the population and of the balance of Nature.

In the circumstances flood control schemes, not infrequently, dealt only with the protection of a few economically important areas where high levees were built; and reservoirs for irrigation or power were meant to produce water for certain specific purposes. The silting up of these reservoirs was no doubt taken into consideration; but, as a general practice, any scheme was considered feasible if the invested capital could be used with profit and written off during the lifetime of the reservoir.

In most cases no attention was given to headwaters. Cutting of forests, ploughing up of pasture land, over-grazing and other bad land-use practices went on unchecked; and all the gains obtained through costly protective works in the lower reaches were lost by bad management in the headwaters. The reasons for such an attitude was not so much lack of knowledge as the preponderance of certain short-term interests over the permanent preservation of water resources. I know of a big 200,000 h.p. water power scheme in which a big natural lake with a surface of about 600 sq. miles would have been drained entirely within 20 years in order to supply during this period power to a very big enterprise. Fortunately, the project never materialized.

Only when such activity intensified floods in the lower reaches of the main streams and the levees had to be periodically raised, when reservoirs built at much cost began to silt up rapidly, and when the ground water-table supply was drained down to complete exhaustion, only then did we realize the importance of headwaters for river valley schemes. In fact, the headwaters, together with tributaries, main river channels and estuaries, form an indivisible organic unit.

The key point of all water management lies in the headwaters where rain falls and whence run-off starts. How fast or how slow the run-off will be, how much of the rainfall can be stored underground, what amount of silt will be carried down the slopes, choking river channels and reservoirs, will depend not only on geological features, slopes and other natural conditions, but also on how we use headwater areas.

Headwaters control or as it is often called 'upstream engineering' involves therefore a great number and variety of complex activities. It is fundamentally concerned with all the elements of the hydraulic cycle. These elements—precipitation, infiltration, evaporation and run-off—are closely inter-connected with climate, temperature, the absorbing capacity of soils, vegetation, including cultivating and cropping systems, and multifarious technical measures, such as irrigation, water supply and drainage works.

Upstream engineering requires a good knowledge of general hydraulic engineering. Just as flood control, irrigation and power problems in the main river channel cannot be solved without the contribution of upstream engineering, so also the problems of headwaters cannot be solved without due regard to their effects on the main river channel. The difficulty in upstream engineering is that it is not limited to a single scheme, but consists of co-ordinated activities of many agencies, the most important among them being the human element, with all its social and economic implications. From the economic point of view, upstream engineering presents difficult problems, mainly because partial solutions, giving prompt returns, are seldom sufficient for solving the major problems.

The effects, too, of upstream engineering measures are more difficult to define than those of other engineering works. We know in general that forests and pastures reduce run-off peaks and increase underground storage and flow of water. But in many cases such a reduction of the run-off affects the total run-off volumes and may be detrimental to the interest of the lower reaches. Likewise the increase of ground water supply at the expense of surface run-off may lead to water-logging in low lands.

Conditions in the Damodar Valley are in this respect more favourable than elsewhere. When the storage reservoirs are completed, there will be still great floods running to waste, and the retention of these in the headwaters will only improve the water balance of the scheme.

The Damodar catchment forms a part of the Chotanagpur plateau. It covers about 7,000 sq. miles up to the confluence of the Damodar and the Barakar. The main plateau are situated between 1,800 and 2,000 ft. above sea-level. Several hills and group of hills are spread over the catchment and reach heights over 3,000 ft. and, in one case 4,500 ft. Almost the whole area is undulating country cut by a large number of nullahs and gullies; and the slopes are in general moderate, except on the hills and at the edges of the plateau.

The geological formations consist mainly of metamorphic rock (granite gneisses with associated schists). In parts of the main valley, these are overlaid by sedimentary rocks (sandstone and shales) containing large coalfields. The soils of the valley are generally shallow, formed by decomposition of these rocks. Their texture, structure and profile characteristics are largely governed by the parent rock. There is practically no alluvium.

Out of the 4.4 million acres of the catchment about 1.6 million are classified as forest, 800,000 acres are paddy fields, 1,000,000 acres tann and uplands and about 800,000 acres wasteland. Owing to intensive destruction of forests and ploughing up of uplands, bad land management especially in the coal mining areas, over-grazing, and bad cultivation methods, the valley is in a state of progressive erosion. According to the information available, the frequency of heavy destructive floods has increased in the past two or three decades.

When studying air photos or surveying sub-catchments one can see a substantial difference between silt transport and gullying of forests or terraced areas as compared

with wastelands. Should erosion caused by bad land management and deforestation not be stopped, there is no doubt that the regime of the river will further deteriorate and the projected reservoirs will prove unable to accomplish their task.

The main objective of the Damodar Scheme is to provide adequate flood control for the lower valley. This should be achieved by construction of storage reservoirs. Water stored in these reservoirs should be used for purposes of irrigation and power. The total average run-off of the united Damodar and Barakar is 8 million acre-ft. per year—the minimum run-off being 4 million acre-ft. and the maximum 12 million acre-ft. The storage capacity for flood control is 2.9 million and for productive use 2.2 million acre-ft. In an average year only 50% of the total run-off can be stored, and out of this only about half can be stored for productive purposes, as the other 50% of the storage volume must be kept empty for sudden floods. In a rainy year only one-fifth of the total run-off can be stored by the reservoirs for productive purpose. Even in a very bad year only 60% of the total run-off can be stored for productive purposes.

Accordingly there is no danger in keeping back water in the uplands which could be used productively by the main project. With the relatively heavy slopes and the shallow depth of soils, water detention measures, will not be detrimental to the main river channel, because in the given circumstances the underground water flow will be relatively rapid and water will eventually reach the main river channels. The delay in the discharge will, on the other hand, be only beneficial, since it will lead to an increase of the dry season discharge at the expense of the flood peaks, the reduction of which is one of the aims of the scheme.

In addition to the direct improvement of the water regime, the introduction of conservation measures and proper upstream engineering will lead to a very substantial improvement in the economic and social conditions of the valley. By retaining water behind terraces and between contour furrows, under the forest litter and in small ponds and detention reservoirs, and by using it in the headwaters for irrigation purposes, agricultural production and welfare of the whole valley will improve. It is fortunate that both objectives of headwater control and conservation works can be achieved by the very same measures.

It is also fortunate that certain conservation measures are already well known and practised in the valley. The most important among them are paddy terraces covering about one-fifth of the total catchment. Another specific feature of water conservation practices in Chotanagpur is to be seen in seepage tanks (ahars). These are built mostly on the edge of high flats with banks thrown up on the downhill side. The ahars are extensively used for the watering of paddy fields. The watering is done by slow seepage. For domestic purposes surface water is normally stored in big excavated tanks and ponds situated in natural depressions or in flat drainage channels. Ponds are formed by earthen bunds.

We shall make extensive use of these existing water conservation practices, which will be included in the overall plan of headwaters engineering. This plan is based on hydrographical units—the sub-catchments. Each sub-catchment will be treated separately according to its specific conditions.

Upstream engineering measures for the improvement of the headwaters can be divided into two groups: (1) Runoff-retarding measures, and (2) Surface storage measures. The objective of the runoff-retarding measures is to reduce flood peaks, check erosion and promote underground water storage through infiltration. This can be best achieved by co-ordinated biological, technical and conservation measures. Afforestation and proper forest management, contour cultivation, strip cropping and improved cultivation methods will have to be combined with technical measures, such as bench and ditch terracing, contour ditching and ridging, and control of natural drainage channels.

Bench terraces, covering at present about 800,000 acres, will continue to remain the main type of terraces. But in the uplands ditch terraces, contour ridges and

ditches will have to be introduced to take care of heavy run-off. These terraces will be connected, wherever possible, with surface storage ponds and tanks. This combination of runoff-retarding and surface storage measures will bring about a valuable improvement in the water management of Chotanagpur.

It is of course essential that spillway channels, connecting the terraces with storage tanks and ponds, should be properly designed. The most economical solution would be the grass spillway channel type. This solution will be used wherever possible. We are carrying out experiments with this type and also with gravel and riprap paved channels.

For the proper design of these runoff-retarding measures, storm runoff calculations are of great importance. We are building our own field plots for runoff experiments, and these, together with discharge measure stations on small nullahs, will give the necessary basic data for the calculations.

As regards surface storage, geological and orographic conditions are generally favourable for the construction of low dams (up to 60 or 70 ft.). Most of these dams will be of the plain rolled earthdam fill type, except where building stone is easily available and rock foundation conditions are good.

Water stored behind these dams will be used for irrigation of land commanded by the reservoirs. Some of the schemes will be small, irrigating only 50 to 100 acres. But there are also quite a few good sites for larger reservoirs, commanding many thousand acres of good irrigable land. Three such schemes ranging from 4,000 to 15,000 acres are at present under investigation.

These irrigation schemes, making use of water in the headwaters area itself, will be an important contribution of upstream engineering to the economic development of the valley. Paddy and Kharif cultivation will be greatly improved by them. But even more important will be the introduction of Rabi irrigation on a large scale, which will change entirely the agricultural economy of the valley. We have already started work on these lines and have built, partly as pilot schemes, four smaller earthdams with storage capacities of 80 to 150 acre-ft. irrigating a total of 500 acres. These reservoirs filled during the early monsoons. More such schemes will be started in the coming season.

Equally important from the conservation point of view is reclamation of wasteland. We have started reclamation work on waste land selected for rehabilitation in the areas to be submerged by our major reservoirs. So far we have only reclaimed 800 acres of badly gullied land; but we are getting sufficient heavy equipment for the reclamation of about 15,000 acres of waste land per year.

Big-scale reclamation work, sub-catchment water management and the introduction of perennial irrigation in the headwaters, with associated technical, administrative and educational measures will involve considerable efforts. The Soil Conservation Engineer will have to use all his inventiveness and experience to find the most suitable and most economical solutions for a great number of small projects, the totality of which must form a well-planned unified scheme for the control of the headwaters.

AGRONOMY AND LAND UTILIZATION

By R. J. KALAMKAR, B.Sc., B.Ag., Ph.D., F.A.Sc., Director of Agriculture, Madhya Pradesh.

(Communicated by Dr. S. L. Hora, F.N.I.)

SUMMARY

The paper deals with the rôle of agronomic science and practice in the understanding of proper classification, use and treatment of land according to its capabilities, with a view to better land use. Proper land use is largely a matter of crop adaptation and soil management. Improper selection of lands to be devoted to agricultural purposes and lack of management in accordance with its capabilities is the cause of greater deterioration of soils. Illustration is given of the soil erosion that has taken place during the course of about 75 years in the cotton growing districts of Buldana, Akola and Yeotmal as determined from the depth of soils of the fields as available in the old settlement records and as determined in the scheme for crop estimating survey on cotton, conducted recently under the auspices of the Indian Central Cotton Committee. The results have shown that a portion of soil which initially belonged to the medium type having depths between 15" to 30" has migrated to the shallower class having depth below 15" as a result of erosion. The degree of erosion has varied from district to district, which could be explained to a great extent in the light of the cropping practices adopted in them. The relation of the yield of cotton to the depth of the soil is also discussed.

The paper focusses attention on the relationship that exists between cropping system and the factors such as soil organic matter, nutrient supply, soil structure, depth of arable soil and the urgent need for developing the rotations on the basis of land use capabilities so as to control surface run-off and soil losses. The importance of manures and fertilizers, adoption of simple tillage practices and engineering techniques for the better use of land are also discussed.

Proper land use is largely a matter of crop adaptation and management which calls for the proper understanding of classification, use and treatment of land according to its capabilities.

The inherent productive capacity of the soil for producing good and large yields depends on the degree of success or failure of soil management practices to maintain—

- (i) Soil Organic matter,
- (ii) Plant nutrient supply,
- (iii) Soil structure—Physical condition of the soil, and
- (iv) Depth of arable soil.

Special emphasis needs to be laid on item (iv), viz., 'Depth of arable Soil'. Erosion of top soil has been a grave danger to agricultural production to meet the ends of a growing population. Any soil management practices which try to keep the top soil where it is, will result in the maintenance of soil productivity and increased yields.

It is not uncommon to have 1" of top soil washed away in as little as 5 or 6 years; productivity has been found to be reduced by at least 10 per cent with each inch of top soil lost and the rate of plant food removed by erosion is about 21 times greater than the rate of removal by agricultural crops. The erosion studies at the Dry Farming Research Station at Sholapur have shown that the annual soil loss amounts to 44 and 29 tons respectively in the usual method of cultivation of rabi jowar and under the cultivation of kharif crops of Bajra-Arhar mixture. At this rate, it would take about 31 years in one case to erode the cultivated layer of 8 inches of surface soil while in the other, 20 years.

Interesting information on the change in the depth of arable soil under a type of cropping system prevalent in the cotton districts of Berar has been obtained in connection with the scheme of crop-cutting experiments on cotton under the auspices

of the Indian Central Cotton Committee, conducted by Panse. The data has been analyzed by Bhide, and relation established between the depth of top soil and yield of cotton. The fields under the cotton survey for a period of three years 1944-45 to 1946-47, were classified according to the old depth record carried out in 1872 settlement as well as the depth actually measured during the survey. The results are shown below along with the yield of seed cotton for different soil depths.

Change in Depth of Top Soil

No. of fields according to soil depth

Depth class	Akola District		Buldana District		Yeotmal District	
	Old Settlement	Cotton Survey	Old Settlement	Cotton Survey	Old Settlement	Cotton Survey
31" and above ..	226	234	130	176	159	159
15"-30" ..	182	92	151	91	131	96
Below 15" ..	152	234	169	183	214	249

Soil Depth and Yield Relationship

Crop-cutting experiments on cotton. Yield of seed cotton in lbs. per acre

District	Above 33"	28"-33"	22"-27"	16"-21"	10"-15"	0"-9"
Akola ..	215	270	243	188	148	125
Buldana ..	255	232	270	165	173	134
Yeotmal ..	270	296	245	188	191	133

The results are a good illustration of the soil erosion that has taken place in the course of about 75 years. The fields which initially belonged to the second group have migrated to the third group as a result of erosion, thereby decreasing the number of fields in the second and increasing them in the third group. In Class I, there is not much difference in the old and new depths. It is possible that even in this class, the deeper soils may have lost some of their surface soil, but this cannot be brought out as complete depths are not measured. It would be noted from the table that, whereas, the increase in the number of fields in the depth class 'below 15"' is 54 per cent in Akola, it is only 16 and 8 per cent, respectively, in Yeotmal and Buldana district. Erosion has been more noticeable in Akola and least in Buldana. While the degree of erosion is dependent, along with other factors, on the type of soil, slope per cent and intensity of rainfall, it also essentially depends upon the cropping system in vogue. Investigations into the causes of these wide differences would materially help to find out factors responsible for erosion or otherwise. The yields were in general, found to decrease with decrease in the top soil. Bhide has prepared a map of the cotton growing districts of Madhya Pradesh showing the rainfall, soil depths and yield contours which bring out clearly the inter-relation of yield with rainfall and soil depth. The map is given in figure 1.

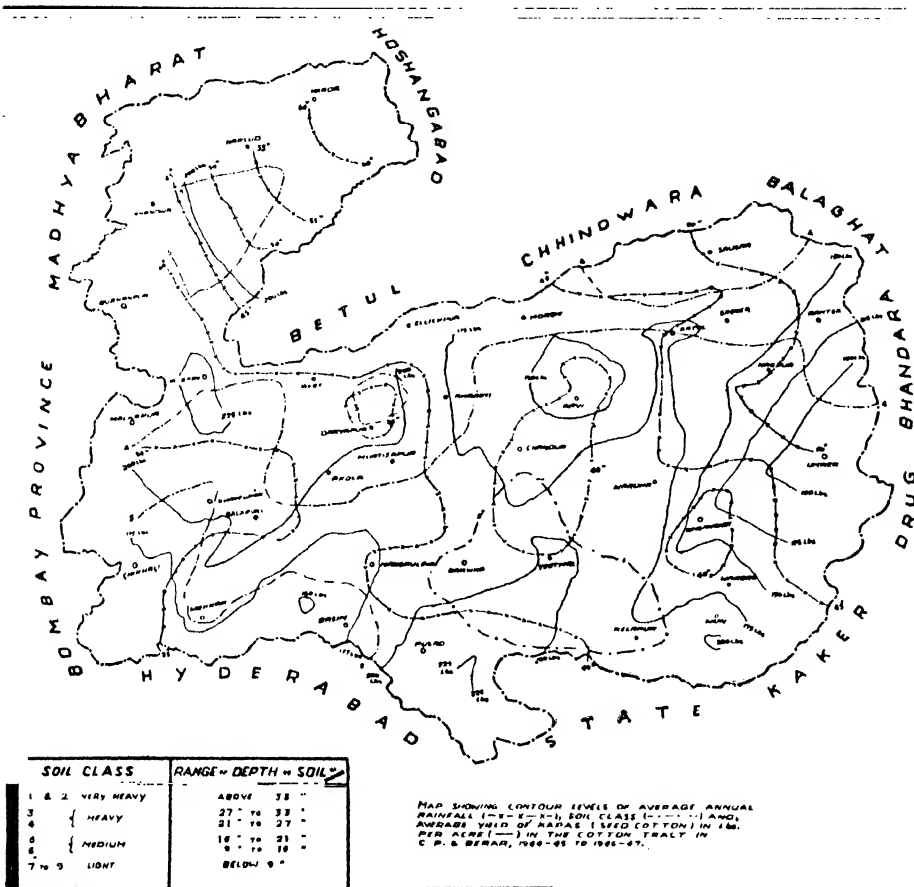


FIG. 1.

As already noted above, proper land utilization calls for the proper understanding of classification, use and treatment of land according to its capabilities. All individual management practices which contribute to soil conservation and its productivity have to radiate from the soil as a focal point.

The importance of crop rotations in general maintenance of soil fertility is well known. Loss of organic matter and nutrient elements and deterioration in the physical properties or tilth of soil are a few of the several ways in which soils may deteriorate under cropping. Continuous cropping depletes the soil organic matter. The choice of crops in a rotation has to be based on the land use capability, which takes into consideration the information in regard to soil type, slope, character and degree of erosion and other physical and land conditions. Some useful work in this direction has already been done for crop rotations with particular reference to sugarcane in the Bombay Province by Basu and similar work on some of the Uttar Pradesh soils has been done by Mukerji and Agarwal.

The growing of legumes in a cropping system is widely recognized as useful in the maintenance of fertility but information in respect of legumes which will be most suitable for this purpose in the different tracts is meagre.

The mixture of crops which includes some leguminous crops takes the place of rotation in many places. This also acts as an insurance against weather. As an illustration of how the practice of growing wheat alone and Birra (wheat and gram in a mixture) differs from tract to tract, the following figures may be of some interest.

Area under wheat alone and Birra

Average of ten years ending 1939-40 (in thousand acres)

Tract	District	Wheat	Birra
Open Cultivation	Saugor	402	72
	Hoshangabad Sub-Division	370	38
Haveli Cultivation	Jubbulpore	111	298
	Narsinghpur Sub-Division	8	154

Suitable crops to be grown in a mixture and their proportion need to be worked out for different soil and climatic conditions.

More scientific work is needed in regard to the effect of crops on those which follow. Amongst points for study are the biological processes, particularly the activities of the nitrogen fixing soil organisms, the effect of legumes on the moisture and nitrogenous status of the soil and the availability of the mineral nutrients, especially phosphates in the different soils.

Strip cropping is another form of rotation and its importance in controlling run-off and erosion and thus maintaining the fertility of the soil is now universally recognized but very little work is done in India. Suitable close growing crops require to be determined for different regions and the width of strips and the seed rates to obtain best results for erosion control under different percentage and length of slopes and types of soils require to be worked out.

One very important point is the importance of grasses in the rotation. It is likely to play an important rôle in the agriculture of our country which would involve change in the type of farming. Many of the lands would be better suited for this. There is urgent need for more production in milk and milk products which will be possible if grasses and fodder legumes are fitted into the rotation. The scope for this, perhaps, appears to lie both under irrigated and dry land farming. Much of the benefit from growing sod crops is due to the influence they have upon aggregation or binding together of soil particles. A high degree of aggregation promotes more rapid infiltration, more air movement within the soil, prevents excessive run-off and less erosion occurs.

The need for evolving suitable crop rotations in agriculture will be increasingly felt particularly in view of irrigation facilities which would be available when the multi-purpose river valley projects materialize, if the fertility of the soil is to be maintained and good yields to be secured under the intensive system of cropping. In the dry farming areas where moisture is a limiting factor, introduction of a fallow in the rotation has a great advantage in the securing of good yields.

The value of manures and fertilizers in increasing the yields of crops needs no emphasis. Crops differ in their nutrient requirements. Some information is available in respect of effect of nitrogen, phosphate, potash applied through bulky organic manures or fertilizers. Much leeway has, however, to be made to determine the dosage, form, time of application and method of application and their combination under different soil and climatic conditions. Very little work is done in India on the long term aspect of assessing the value of organic manures. Green manuring, phosphatic manuring of legumes and general aspects of stock feeding and farm yard manure need to be investigated with a view to utilize the land properly. Besides,

investigations regarding the general manurial requirements of the crops as referred to above, much work is needed on other soil ameliorants including trace elements. Special emphasis needs to be laid on trace elements, liming and the reclamation of alkali lands which have gone out of cultivation.

For proper land use, apart from devising suitable protective soil building crop rotations and their manuring, there is also need for resorting to suitable tillage or cultural methods and simple engineering practices. In the first category may be included such items as depth of ploughing, repeated shallow cultivations during the monsoon period to conserve water, listing, rates, times and methods of seeding, sub-surface tillage and adopting these practices on the contour. For proper land use and erosion control, contour tillage is a key practice. If a sloping field is ploughed, planted and cultivated around the contour level instead of up and down the slope, each row and plough furrow acts as an impediment to the downward rush of run-off water. This slows down the velocity of the water and enables more of it to enter the soil and in turn, diminishes the power of run-off water to carry soil along with it.

In the other category, viz. simple engineering practices, may be included terracing which implies building ridges of soil of particular height which should be along the contour lines of sloping fields in order to slow down and hold as much as possible of the water which would otherwise flow downhill with increasing velocity. Earth bunding and bench terracing have been known and practiced in parts of India for a very long time. These practices need to be improved and extended. Some work has been done in this direction in the Bombay Province. Specifications of the terraces and the intervals at which they are to be constructed need to be worked out for different soils with their slopes under the condition of the intensity of rain obtaining in the tract. In some cases, check dams and grassed waterways need to be constructed to check the gullies.

In short, Agronomic science and practice has much to contribute towards better land use and conservation. Some of the problems that need attention in this behalf have been outlined in the paper.

SOME FACTORS CONCERNING THE TRANSPORT OF SEDIMENT BY RIVERS¹

*By J. B. AUDEN, M.A., Sc.D. (Cantab.), F.N.I., Superintending Geologist,
Geological Survey of India, Calcutta.*

SUMMARY

The paper discusses the problem of capacity and competence of rivers in transporting sediment, based on the pioneer work of Gilbert, and subsequent elaborations by Rubey, Quirk and Mackin. It is suggested that sufficient attention has not been paid in silt studies, as they effect engineering projects, to the power functions between capacity and competence with bed velocity, and indirectly therefore with discharge. Data collected by the River Research Institute, West Bengal, and by the CWINC research stations at Hirakud and Barahakshetra, indicate that the silt contents of the Damodar, Mahanadi and Kosi rivers are higher than the normal upper limits provided by A. N. Khosla's formula. The special geological conditions relevant to the Kosi and other Himalayan catchments are outlined. The possibility is then considered of the erosion and transport of the bed sands of these rivers under conditions of peak discharge, and the increased cross-sections thus developing which should be considered in estimating flood discharges. Finally the paper discusses the effect of the construction of dams on the retention of silt, and the fact that the flood waters which will spill over the dams will not be flowing to full capacity or competence. From this consideration it is suggested that the 'fixed' sand deposits below the Maithon and Panchet dams, which are now used for sand-stowing, may be eroded. Another effect of retention of sand as deltas in the headwaters of the reservoirs will be the aggrading of river beds upstream. Such aggrading might be a menace to structures such as the Sindri Fertilizer Plant, were it not for the proposed upstream control of the silt charge by construction of dams nearer the tributary headwaters.

CONTENTS

	<i>Page</i>
1. Introduction	501
2. Capacity and Competence	502
3. Data about Suspended Load	503
4. Competence	505
5. Tractional Load	505
6. Work of Rivers during periods of Flood Discharge	506
7. Siltation Formulæ	508
8. Deposition during the Pleistocene	509
9. Effect of Construction of Dams	509
10. References	511

1. INTRODUCTION

Nearly four years ago the writer prepared a small report for the then Department of Labour, Government of India, to assess on limited evidence the quantity of silt brought down by the Damodar river, and the effect which the construction of dams would have on sand supplies used for sand-stowing in the coalfields. It cannot be said that our knowledge has much increased since then, but it is thought worth while to review the data once more from the slightly different approach of the geological principles underlying the argument.

My colleague, Mr. A. B. Dutt, has discussed in a separate contribution to this Symposium the quantities of sand now present in the beds of the Damodar and related rivers and the amounts required for sand-stowing operations. This present paper is concerned more with questions of the capacity of rivers to transport sand and the effects of dam construction on the annual increments.

¹ Published by permission of the Director, Geological Survey of India.

The problem of sand supplies for stowing operations in the Jharia coalfield was discussed 20 years ago by C. S. Fox (1930, p. 106), who classified the sand into two categories:—

- (a) 'Fixed' deposit perennially present in the river bed; regarded as 80 m. tons between Amlabad and the end of the coalfield.
- (b) 'Current' deposit brought down annually by floods; regarded as 25 m. tons.

The designation 'fixed' deposit was not intended to imply that the sand in the river bed was immovable. Fox himself suggests that the top 6, or even 8, feet of sand in the river bed would be in movement during floods. The sand of the river bed must indeed be carried down both as suspended and as tractional (or bed) load during floods, and further sand would be dropped from upstream as discharge and velocity diminished. In this sense only is it permissible to regard these deposits as fixed, for in reality the sand must be for ever changing and renewed, and is not necessarily of constant thickness from year to year. The sand-stowing operations remove large quantities of sand annually from the river beds and the areas of extraction are invariably filled up by the subsequent monsoon floods. For instance, as much as 1.5 million tons of sand are required annually by only 3 collieries in the Raniganj coalfield.

2. CAPACITY AND COMPETENCE

The question of the quantity of silt carried annually by rivers is highly involved, since it is connected not only with the hydraulics of river flow over beds of varying gradient, hydraulic radius, and bottom conditions, but on the geological nature of the catchment, on climate, and on the effects of human action, such as de-forestation and unsound systems of cultivation. Very divergent estimates have been made, partly as a consequence of the many different types of catchment studied, but partly because experimental studies of suspended load have varied in accuracy. The primary difficulty is to make any reliable estimate of suspended silt content during periods of peak floods and high flood velocities. Estimates of tractional or bed load are even more uncertain.

Two basic conceptions involving velocity coefficients were developed by Gilbert 36 years ago, and have been elaborated by Twenhofel, Rubey, Quirke and Mackin in more recent years.

Capacity may be defined as the maximum load that a stream can carry in suspension. Much depends on the conditions of the stream: whether or not the stream flows over a sandy bottom; the grade size of the silt; and the settling velocities of the largest particles carried. Relevant to most rivers of peninsular India is Rubey's statement that 'in a stream free to pick up much sand and gravel as its velocity is increased, the unit width load will vary roughly as the third power of the "bed" velocity'.

Competence may be defined as the ability of a stream to transport load in terms of dimensions of particles. Rubey gives the rule as follows:—

'The weight of the largest debris moved by a stream varies as the sixth power of the "bed" velocity.'

The largest particles moved in a stream would form the tractional load, while the smaller particles moved would be transported as suspended load.

Rubey discusses in detail the meaning of the term 'bed' velocity, showing that it is reduced by a low hydraulic radius, such as is common to many rivers of the Indian peninsula, and by a decrease in channel smoothness. He points out (p. 132), however, that bed velocity is most sensitive to changes in the mean velocity and only very slightly sensitive to changes in the roughness ratio.

Quirke (1945, p. 129) elaborates the conception of capacity and expresses the effective energy of a stream carrying a load in terms of $V-x$, in which ' V ' equals the velocity of flow unimpeded by any load, while ' x ' represents the reduction in velocity due to the load. In shallow rivers, supplied with an abundance of sand load smaller in size than the maximum for which the stream is competent, such as are prevalent in peninsular India, Quirke remarks that the factor ' x ' must be large and that the capacity may vary as $(V-x)^{3\pm}$. He also cites the formula developed by Lechalas, and earlier discussed by Gilbert (1914, p. 195), for movement of rivers over sandy bottoms in France as:—

$$C = K (V_m^2 - k)$$

where capacity varies as the square of the mean velocity, with two empirical constants. Even with an assumed exponent as low as 1.5, a fourfold increase in the velocity involves an eightfold enlargement of the power product to which capacity would be related. Whatever the actual exponent may be for particular local conditions, it is clear that the curve of silt load as a function of velocity is parabolic, and that the load of suspended silt during short periods of exceptional peak floods may be extremely large.

Leighly (1934, p. 463) has also stressed the importance of turbulence in stream transportation, and has shown that in the case of a normal symmetrical cross-section of a stream with relatively large hydraulic radius, the most active erosion of bed deposits is below two areas of maximum turbulence near the stream bottom and lateral to the axial zone of maximum surface velocity. Most peninsular rivers have a low hydraulic radius almost approaching the relatively small mean depth of the river and the zones of turbulence in them are clearly much more irregular. Turbulent flow itself varies with a power of the velocity.

Few data are available in this office regarding velocities of flood discharge flow. It is said that the Kosi river, which flows through a narrow gorge in the Nepal Himalaya, reached a surface velocity of 28 ft./sec. in 1948. In the case of wide flat-bottom rivers, such as the Damodar, discharges of the order of 500,000 cusecs are accompanied by surface velocities of 15 ft./sec. and analogous bed velocities. The maximum recorded velocity of the Mahanadi at Sambalpur in 1948 was 8.03 ft./sec. for a discharge of 948,000 cusecs. Observations of suspended load are presumably not very reliable in the case of discharges exceeding 5 ft./sec., and may be almost impossible during times of peak floods, such as occurred in June 1950 on the Teesta river, which is said to have passed a record discharge of 600,000 cusecs through a gorge from a mountain catchment of only 4,800 sq. miles.

3. DATA ABOUT SUSPENDED LOAD

According to the Report of the Advisory Committee on the Hirakud Dam Project (June 1948), the total run-off at Hirakud in 1947 was 39.18 m. acre-feet, and the silt yield was 33,235 acre-feet, for a catchment area of 32,200 sq. miles. The mean annual run-off at Hirakud is taken to be 50 m. acre-feet and, on the assumption that the mean silt charge of a catchment is carried in a year of mean annual run-off, the silt yield for the latter year was estimated proportionally to be 42,500 acre-feet, or 1.32 acre-feet per square mile. Subsequent data obtained by the Hirakud Research Station under the charge of Dr. R. C. Hoon indicate that for the three years 1947-49 the average discharge was 35.75 m. acre-feet, with an average suspended silt content of 29,891 acre-feet, and a silt intensity of 0.93 acre-feet per square mile. If 50 m. acre-feet is still regarded as the average run-off, proportionality would suggest that the average intensity of silting would be 1.3 acre-feet per square mile. The figures given below for the Barakar river suggest, however, that it is unsafe to assume simple proportionality, since the silt content may be related to exceptional short periods of high-intensity precipitation and run-off, rather than to the total annual run-off.

On page 29 of the Preliminary Memorandum on Unified Development of the Damodar River it is stated that observations made during the monsoon seasons from 1939-41, inclusive, indicated that the proportion of silt carried by the Barakar river at Barhi amounted to approximately 1/350 of the average flow. It was assumed that for the Damodar catchment as a whole the proportion would be 1/500. If this proportion is applied to the mean annual run-off at Rhondia of 8.04 million acre-feet, the quantity of silt would be 16,080 acre-ft., equivalent to 28 million tons at 90 lbs./c.ft. Since the catchment area above Rhondia is 7,690 sq. miles, the intensity of silting on the above assumptions would be 2.09 acre-ft. per square mile per annum. These data have now been supplemented by fuller silt observations carried out by the River Research Institute, West Bengal, under the guidance of Dr. N. K. Bose (1949, p. 39):

Monsoon volumes of discharge of Barakar river near Giridih and Kulti together with silt charge, for June to October inclusive

Catchment Area	Barakar (Giridih) 1,540 sq. miles			Barakar (Kulti) 2,500 sq. miles		
	Discharge in million acre-feet.	Silt charge in acre-feet.	Siltation Intensity: acre-foot per sq. mile.	Discharge in million acre-feet.	Silt charge in acre-feet.	Siltation Intensity: acre-foot per sq. mile.
1945 ..	1.100	2,511	1.64	1.803	..	..
1946 ..	2.121	4,439	2.88	3.027	5,806	2.32
1947 ..	1.653	4,399	2.86	2.501	3,056	1.22
1948 ..	1.058	1,437	0.96	2.330	2,171	0.87
Average 4 years and 3 years .. ..	..	3,205	2.08	..	3,678	1.47

The intensity of siltation for the whole catchment based on the reduced value of the Barhi determination agrees exactly with that subsequently found in the Barakar river at Giridih, but is too high for the Barakar further downstream at Kulti. It is likely therefore that siltation intensity on the Damodar at Rhondia would be even lower than on the Barakar at Kulti, and might be of the order of 1.3 acre-ft. per square mile.

Finally, data may be given for silt content during periods of flood discharge, the data being obtained from Buckley (1928, p. 148) and Bose (1948, p. 3; 1949, p. 37):

	Ounces per cubic ft. or grammes per litre.	
1. Suttlej 7-7-1894 (Buckley)	29.4	
13-6-1895	25	
2. Kistna 27-7-1900 (Buckley)	20	
22-6-1901	23.8	
3. Barakar, Giridih 1-8-1947 (Bose)	14	
	10 for more than	
	13 hours.	
4. Damodar, Ramgarh 7-7-1946 (Bose)	22.77	
7-7 to 8-7-1946	11.78 for 24	
	hours.	

At Ramgarh on the Damodar river the silt charge volume during $2\frac{1}{2}$ days in June 1948 was 335 acre-feet, for a catchment of 1,250 sq. miles, and was equal to about 30 per cent of the total monsoon silt charge. In a single day (1-8-1947) at Barakar (Giridih) the volume of silt charge was 2,568 acre-feet, which was higher than the total volume of silt charge for the individual years 1945 and 1948. On this day the silt content exceeded 14 oz./c.ft. for a maximum discharge of 260,000 cusecs, and was greater than 10 oz./c.ft. for more than 13 hours during the high stage.

These figures demonstrate the immense activity of rivers during peak floods, throughout which periods, lasting only a few hours, the full implications of the power function become manifest, and the greater part of the geological work is done. When it is remembered that the figures refer only to suspended silt, and not to bed load, it is clear that the total activity of rivers during floods is even more impressive.

4. COMPETENCE.

Work done by CWINC on the suspended silt of the Mahanadi river in 1947 shows that 76 per cent of the total observed load was below 0.075 mm., 13 per cent between 0.075 and 0.20 mm., and only 11 per cent greater in size than 0.20 mm. Data concerning the grading of the Mahanadi bed sands are lacking. Similar small percentages have been found in the river waters of the Damodar basin with respect to the coarser particles above 0.611 mm. in diameter. The maximum percentage of such particles recorded for the monsoon discharges was 7.7 per cent at Barakar (Kulti) in 1946 (Bose, 1949, p. 40). The bed sands of the Damodar river from Argada to Champadaga over a distance of 200 miles were found by A. K. Roy (1942) to be as follows:—

	1	2	3	4	5
>0.421 mm.	.. 30.60	32.20	9.00	28.00	20.12
0.211-0.421	.. 46.50	49.01	69.02	62.05	63.64
0.139-0.211	.. 18.00	5.14	17.21	3.77	8.77
<0.139 ..	.. 4.20	13.01	4.09	5.47	5.06
Greater than 0.211 mm.	77.1	81.2	78.02	80.05	83.76

The critical bed velocity at which movement of sand greater than 0.20 mm. diameter starts is of the order of 0.05 ft./sec., whereas sand particles with diameter 4 mm. begin to move with a velocity of 1.4 ft./sec. (Rubey, p. 133). It is evident therefore that the coarser fractions of these Damodar sands begin to be eroded with relatively insignificant bed velocities.

It is seen that the Damodar bed sands have higher percentages of coarse grades than the silt obtained from suspension in the river itself. The silt analyses refer only to suspended load near the water surface and do not indicate the true picture of material transported during flood periods in the lower depths of the moving water.

5. TRACTIONAL LOAD

The quantity of tractional or bed load moved by streams is known with even less certainty than the suspended load. Twenhofel (1950, p. 222) cites estimates in Europe of tractional as a percentage of bed load which vary from 14 to 30 per cent, whereas in some exceptional American rivers the tractional and suspended loads have been considered to be almost equal. It is probable that the ratio will vary in the same stream according to different velocity conditions, since the size of particles moved by traction varies with a higher power of the bed velocity than the load carried in suspension. It is difficult of course to relate the amount of bed load directly to competence, since competence refers to the maximum size of particles that can be moved and not to the quantity, but it has been shown that in the case of a river able to put into motion progressively coarser grain sizes, there is a moderately close

relationship between the quantity of debris in motion and the largest grain size that is being translated (Mackin, 1948, p. 469). During low winter discharges of many rivers the sand may be seen through the clear shallow water being moved as bed load without any suspended load being present at all, whereas under flood conditions the suspended load is abundant, but the turbidity arising from it obscures any direct observation of the quantity being moved as bed load.

The ratio will vary also between different streams, depending on the size of the bottom materials. Mackin (1948, p. 470) has pointed out that the total load carried will be greater for a given velocity for small sizes than for larger sizes, and has argued that for rivers such as the Damodar, which have particle sizes clearly not up to the full competence of the river during peak discharges, it is capacity which is the critical factor, and the total load carried per unit width may vary as a power of the bed velocity which is higher than the third power. In such a case, with bottom sands of relatively small particle size, it is probable that tractional load may be relatively unimportant under large discharges, and suspended load forms the major part of the total load. On the other hand, with rivers such as the Kosi, which have abundant coarse boulders distributed in rapids throughout the montane course, the fraction of bed load which moves under high velocity conditions may increase relative to the suspended load, and increased competence is in a sense a measure of the amount of tractional load.

6. WORK OF RIVERS DURING PERIODS OF FLOOD DISCHARGE

Dr. N. K. Bose has suggested to me that the experiments on velocity have only been carried out within a very limited velocity range, and that extrapolation to the higher velocities encountered during large discharges is probably unsound. The maximum velocity in Gilbert's laboratory experiments appears to have been 3 ft./sec. While it is possible that the exponent may change with very high velocities, the geological evidence for major activity at times of high discharge and velocity is unequivocal, and does not suggest that the rule is significantly modified in the direction of diminished capacity under such conditions. To account for the lack of correspondence between theory and experimental results it might be assumed either that the silt supplies from the catchments are small, or that the experimental results are not representative for the higher ranges of discharge and velocity. It is true that some Indian rivers do not yield much silt, such as the Cauvery at Mettur. But since soil erosion is prevalent in the catchments of most Indian rivers, and since these rivers are proved to be very silty during flood periods, it is unlikely that there is a shortage of silt supply during periods of concentrated precipitation and run-off. Moreover, the rivers in their lower reaches flow over 20–80 feet of wide sandy bottom, part at least of which is perennially water-born, and these sands are witness therefore of higher grade sizes being moved than are recorded in the silt tests.

What rivers are capable of doing during peak discharges is clear from the nature of the Colorado river at the Boulder (Hoover) dam. An inner gorge 75–80 feet deep below the rock benches on either side, and some 120 feet below river bed level, was found to be pitted, fluted and pot-holed. Moreover a sawn plant of wood was found embedded in gravels at the edge of the inner gorge. It could only have reached this position provided the whole mass of gravels from top to bottom had been in a condition of buoyancy and turbulent movement, during a historically recent flood.

Corroborative evidence has very recently come to light of the same feature to the Kosi dam site in Nepal. My colleague, Mr. M. S. Jain, informs me that a piece of fresh wood has been found in diamond drill hole No. 201, which is the centre hole of the toe alignment, at a depth of 42 feet below the top of the bed sands and $3\frac{1}{2}$ feet above ledge rock below the sands. The average thickness of the bed sands, which lie below 15 feet of quiet water during periods of low discharge, is 43 feet, with a range from 26 to 64 feet in 15 holes. The occurrence of such wood, almost

at the bottom of the bed sands, clearly indicates that during flood discharges the whole of the thickness of these sands must be in a state either of suspension or of movement sufficient for the wood to have been left in that deep position. Another piece of wood was found from $21\frac{1}{2}$ to $25\frac{1}{2}$ feet below the top of the bed sand, and 10 feet above bed rock, in wash-boring No. CD4.

As already stated, Fox considered that the top 6-8 feet of the bed sands of the Damodar may be under suspension during floods. This is probably an underestimate for large discharges and it is conceivable that the whole thickness of sands may periodically be in motion. From data provided by Mr. A. B. Dutt, the average thickness of the bed sands of the Barakar river between its confluence with the Damodar and the Kalyaneswari temple, near Maithon, is 43 feet, with cross-sectional ranges between 36 and 54 feet. But at the Maithon dam site, in the section where the river is at its narrowest (1,000 ft. wide) the bed sands are found from detailed drilling at 200 ft. centres to average 62 feet, with a range of 38 to 85 feet. It is of course arguable that the deeper scour at the narrowest section of the river took place during an earlier regime of the river, and has subsequently been filled up by mainly non-scouring sands. But it is also possible that, as in the case of the Colorado and Kosi rivers, the whole thickness of bed sands at Maithon may be scoured out and transported during floods such as occurred in 1823, 1840, 1913, 1935 and 1942, and that the deeper scour in the Maithon defile belongs to periodic peak discharges of the present river regime. The drill records at the Maithon site do not indicate any break in the nature of the bed sands throughout their depth, but suggest rather an essential continuity and a single regime.

This problem is of relevance to estimates which are made of peak discharges, for it may be necessary to calculate the cross-sectional area of moving water not only upwards from bed-sand level, as it occurs during small discharges, but from the base of the bed sands resting on rock. In the case of the Maithon cross-section, this would involve an additional area of some 62,000 square feet, while in the Kosi gorge, Nepal, the additional peak flow area would be of the order of 12,000 sq. feet.

This enlarged cross-sectional area, set in motion during floods, will naturally involve greater flood discharges than are normally accepted on the basis of a cross-section taken down only to the top of the bed sands. If all the factors involved in discharge are correctly assessed, the ratio of the calculated run-off to the actual run-off should approximate to unity. After allowance has been made for discharge into rivers from springs and diffuse effluent seepage from the ground water, and for increments due to snow-melt and glacier-melt water, the discharge from streams should not exceed the actual precipitation over the catchment. This will set a limit to the actual discharge which can be expected from the enlarged cross-section, and may lead to the conclusion that the bed velocities are much smaller than the surface velocities. Such considerations apply to the Damodar river, where the total discharge below the main tributaries over the Anderson Barrage is known, and forms a check to calculations based on enlarged cross-sections. But uncertainty may exist about the representative character of the rain-gauge stations over a catchment, particularly in the almost unknown regions of Nepal, Bhutan and Upper Assam, and it seems advisable to consider the possibility of the real discharges in times of flood being greater than those hitherto accepted in the little studied rivers of the eastern Himalaya.

It may be noted that, whereas the bed sands of the Kosi river at the dam site are relatively fine, with only occasional boulders, the boulder gravels downstream thereof at Chatra are very coarse. These gravels have been derived from upstream of the dam site and must have passed through the gorge during periods when river competence was much higher. This points to the complete flushing out of all the fine bed material at the dam site during periods of flood discharge. The fact that only sands are dropped at the site during declining discharges, while gravels are confined to the rapids above and below the site, is admittedly difficult to explain.

Alternations of rapids and still sections in the longitudinal profile of a river imply sudden changes in velocity, with acceleration and deceleration. It is possible that the deceleration which arises where water passes from the rapids to the still sections has a greater influence during a waning flood on competence than on capacity, since competence is more sensitive to changes in velocity than capacity. This would indicate that the coarse detritus carried and moved by a river in flood tends to be deposited with declining discharges in the rapid sections, where the deceleration is at a maximum.

7. SILTATION FORMULAE

From a study of over 200 reservoirs A. N. Khosla has developed an empirical rule for silting from catchments exceeding 1,000 sq. miles in area. This states that the annual rate of sedimentation per 100 square miles of catchment has a *normal upper limit* of 75 acre-feet. It is probable that the majority of reservoirs from which this rule was derived are located in the temperate climatic zone. Many of the reservoirs are located in the Western States of the U.S.A. where climatic and geological conditions are broadly similar.

The average rate of silting in the Mahanadi at Sambalpur, for the years 1947-1949, is considered to be 0.93 acre-feet per square mile per annum, and possibly 1.3 acre-feet for an average discharge. The average observed silt content of the Barakar river near Maithon for 3 years is 3,678 acre-ft. or 1.47 acre-ft. per square mile, which is double of that indicated from the formula. In the case of the Kosi river in Nepal, the annual silting rate is now determined by CWINC to be 5.18 acre-feet per square mile per annum, for the 3 years 1947-1949, which is almost 7 times the rate derived from the empirical rule.

The Kosi river is of interest in showing a combination of peculiar conditions:—

- (a) the Himalaya is a region of very recent overthrusting and folding, and the river profiles indicate active downcutting concomitant with even more recent isostatic elevation;
- (b) many of the southern tributaries of the Sun Kosi river have catchments in outcrops of Siwalik clay, sand-rock and cobble conglomerates. These rocks are very poorly compacted and both the argillaceous and arenaceous facies are eroded with the greatest of ease;
- (c) the Arun catchment in Tibet flows through extensive areas of Jurassic shales without vegetal cover;
- (d) within the catchment of the Sun Kosi, Arun and Tamur rivers lie the highest peaks of the Himalaya, with extensive snow fields and many large glaciers. The glaciers effect strong abrasion of their rocky beds, and the rock flour is carried down during the months of snow and ice melt;
- (e) much deforestation has taken place in the lower ranges.

These factors all conspire to make the Kosi a very silty river. The Kosi has indeed built up a sub-delta of coarse sands and gravels, over 3,000 square miles in area, upon the Gangetic plain, and it is likely that the capricious deposition of coarse detritus, where the river debouches into the plains south of Chatra, is one of the factors responsible for the shifting course of the river. Another factor has been briefly mentioned elsewhere (Auden; 1949, p. 328). The Tista river has also had a very variable course south of Sevoke, which is probably due in part to erratic deposition of gravels at the débouchure.

Similar geological conditions apply with slight modifications to many Himalayan rivers in the catchments of which occur Siwalik outcrops and glaciated ranges. The Karnali river has a catchment area of 20,600 sq. miles in the western Nepal Himalaya in which are present both high peaks, many glaciers, and extensive areas of Siwaliks. West of longitude 77° the

glaciers of the Himalayan range are somewhat less important, but the outcrop of Siwalik and Middle Tertiary rocks expands to 30–50 miles in width and forms considerable areas in the catchments of the Sutlej, Beas, Ravi and Chenab rivers. The very extensive and thick terraces of boulder gravels along the flanks of the Kali Gandaki river in central Nepal point to an earlier, but still recent, regime of the river when capacity and competence must have been exceptionally high.

It must be accepted therefore that the rate of silting in Northern India is exceptionally high, and does not conform to conditions characteristic of more temperate climates and orogenically less active terrains. This departure from temperate norm must be allowed for in estimating the life of reservoirs.

8. DEPOSITION DURING THE PLEISTOCENE

The Siwalik rocks (Middle Miocene to Lower Pleistocene) which form a zone of outer foothills at the foot of the Himalaya for a distance of 1,500 miles of arc, represent an orogenic facies deposited in front of the rising Himalayan chain. These rocks vary from 15,000 to 20,000 feet in thickness and die out radially, away from the mountain arc, under Gangetic alluvium. It would be safe to assume a total average width of Siwalik formations, exposed in present outcrops, and concealed below the alluvium, of 50 miles. The whole of this mass of sediments has been deposited probably well within 10 million years.

After early Pleistocene folding and faulting had thrown up the Siwaliks and caused their partial erosion, the Gangetic alluvium accumulated in a downwarp just in front of the Siwaliks. The Gangetic alluvium reaches a maximum thickness in North Bihar, where it may be over 6,000 feet. This pile of sediments has been deposited within the Pleistocene period of about 600,000 years' duration. If a prism of alluvium 100 miles wide is taken radially from the Himalayan arc, one mile wide, and 2,000 feet thick, the volume of sediment is 5,580 billion c.ft. Assuming that this has been eroded from a rectangular area across the Himalayan arc 100 miles long and one mile wide, during a period of at most 600,000 years, the rate of sedimentation is approximately 2 acre-feet per square mile per annum, which is 40 per cent of that of the present Kosi river. The closeness of the figures is of course fortuitous and depends on the assumptions made. It may be objected that the southern part of the Gangetic alluvium is derived from the peninsula, while some of the Himalayan drainage now comes from across the Himalayan axis. Nevertheless, the assumptions made are conservative, because only a part of the width of the alluvial Gangetic alluvium has been taken into account, and the thickness of the alluvium is likely over most of the zone extending 100 miles outwards from the Himalaya considerably to exceed 2,000 feet. Moreover, the period of 600,000 years is probably excessive since the pre-alluvial Siwaliks extend up into the Pleistocene, and the alluvium cannot represent the whole time considered to be covered by the Pleistocene. This calculation has been put forward not for any precise quantitative purpose, but merely to provide an approximate indication of magnitudes when dealing with orogenic sedimentation.

9. EFFECT OF CONSTRUCTION OF DAMS

The limitations of space imposed on this Symposium do not permit of any extended discussion of the effects of the dams on the migration of sand to the places from which it is now extracted for stowing.

There is no doubt that the whole of the gravel and sand brought down by rivers will be retained by the reservoir basins, mainly as deltas in the headwaters where the higher velocity water enters the relatively still impounded waters. It is probable that some of the finer silt grades may pass over the spillways, but the water which is spilled over the dams will most certainly not be transporting to full capacity or competence.

In so far as the reservoirs are designed for flood control, peak floods will be eliminated except in the event of a second cyclone occurring in the catchment immediately after a reservoir has been filled by run-off from a previous one. Nevertheless, in the latter part of the monsoon considerable discharges must be expected from the reservoirs.

Since these waters will be almost silt-free, they will be flowing over the bed sands downstream of the dam with potential ability to take up sand to satisfy the particular velocity and volumetric conditions of the regulated flow. It would appear therefore that the effect of the construction of dams will be to cause erosion of the bed sands below them, of comparatively fine particle size, by the almost silt-free spill waters, and a gradual diminution in the reserves of the so-called fixed deposits, which under the new conditions would receive little or no increments from upstream. In the probably not too rare event of a storm hitting the Damodar basin within a month after the reservoirs have been filled by a previous one, large discharges of the order of 200,000–300,000 cusecs may be expected over the Maithon and Panchet dams which could, according to theory, remove a great deal of the bed sands below them. This is a factor which the coal companies should bear in mind in future planning. It may be advisable to shift the locations of sand supply to the deltas which will grow at the headwaters of the reservoirs, though this will involve a greatly increased haulage. The quantity of sand reaching these deltas will certainly be diminished, however, by construction of dams upstream of the Maithon and Panchet reservoirs.

Another point may be stressed. As the deltas build outwards into the reservoirs, they also aggrade. In a very able discussion Mackin (1948) has shown that the aggradation spreads with great rapidity for long distances upstream, and may effect lines of communication and also towns. The Sindri fertilizer factory will be near the headwaters of the Panchet reservoir and, without upstream development, a delta would be built up considerably above the elevation of full supply level of the reservoir. But in this case, the construction of the Aiyar and Konar reservoirs upstream of Panchet should materially control the entrance of silt into the Panchet reservoir and lessen the tendency of aggradation. Aggrading delta formation should also be under observation at the headwaters of the Hirakud reservoir up the Ib river. If construction of the Dudh Kosi dam is delayed, intensive gravel formation at the headwaters of the main Kosi reservoir will tend to fill up the valley and increase the excavation necessary for the foundations of the Dudh Kosi dam.

Finally, the question of navigation below storage reservoirs may be raised. Mackin (p. 495) showed that the reduction of peak discharges may result in aggradation of the trunk stream below major tributary junctions, since the controlled discharges are no longer able to move much of the detritus delivered to the main channel by flash floods in the tributaries. This case is an exception to the general rule of greater down-cutting in trunk streams below storage dams, but may be very relevant to the question of navigation. For aggradation at the confluences of silty uncontrolled tributaries with main rivers on which storage reservoirs have been built may render navigation at those points more difficult. The Tel river below the Hirakud dam, and the Adjai river below the Maithon and Panchet dams, are cases in point. The construction of the Tikapara dam below the Tel confluence with the Mahanadi would of course eliminate the difficulty on that river by creating a navigable reservoir.

CONCLUSION

The object of this discussion has been partly to emphasize the power functions of capacity and competence with velocity, and partly to suggest the modifications which the structure, recent tectonic activity, and climate of northern India, are likely to impose on empirical rules of silting derived from other, in the main less revolutionary, environments. In so far as the life of reservoirs is concerned, it

would appear necessary in many catchments in northern India to allow for a greater rate of siltation than would be indicated from the rule under discussion.

10. REFERENCES

- Auden, J. B. (1946). Silting on the Damodar Basin and Sand-Stowing. Unpublished Report of the Geological Survey of India.
- (1949). A Geological Discussion of the Satpura Hypothesis and Rajmahal Group. *Proc. Nat. Inst. Sci. Ind.*, 1, p. 315.
- Bose, N. K. (1948). Appendix to the Annual Report of the River Research Institute, West Bengal, 1946.
- (1949). Annual Report of the River Research Institute, West Bengal, 1948.
- Fox, C. S. (1930). The Jharia Coalfield. *Mem. Geol. Surv. Ind.*, 56.
- Gilbert, G. K. (1914). The Transportation of Debris by Running Water. *U.S. Geol. Surv.*, Prof. Paper, 86.
- Khosla, A. N. (1947). Mahanadi Valley Development; Hirakud Dam Project: Government of India.
- (1949). Special Techniques in Water Storage Conservation: Sand Storage, Sedimentation Control, U.N.E.S.C.O. (Water 5 (c)/1).
- Leighly, J. (1934). Turbulence and the Transportation of Rock Debris by Streams. *Geog. Review*, 24, p. 453.
- Mackin, J. Hoover (1948). The Concept of the Graded River. *Bull. Geol. Soc. Am.*, 59, p. 463.
- Quirke, T. T. (1945). Velocity and Load of a Stream. *Journ. Geol.*, 53, p. 125.
- Roy, A. K. (1942). On the Heavy Mineral Assemblages of the Damodar River. *Rec. Geol. Surv. Ind.*, 77, Prof. Paper, 6.
- Rubey, W. W. (1938). The Force required to move Particles on a Stream Bed. *U.S. Geol. Surv.*, Prof. Paper, 189-E.
- Twonhofel, W. H. (1950). Principles of Sedimentation, New York.
- Preliminary Memorandum on the Unified Development of the Damodar River: Central Technical Power Board, Government of India, 1946.

SAND-STOWING

By A. B. DUTT, M.Sc., F.G.S., Geologist, Geological Survey of India, Calcutta.

(Communicated by Dr. W. D. West, F.N.I.)

SUMMARY

Sand-stowing was first tried at Ballarpur about 1914 and subsequently introduced in the Jharia, Raniganj and other coalfields. Stowing has both advantages and disadvantages; the main objection is economic because it raises the cost of production of coal.

Hydraulic stowing is most suitable in India as there are apparently adequate supplies of sand and water in the rivers near the coalfields. The Coal Mines Stowing Board, set up in 1939, for providing for safety in coal mines by stowing, grants assistance for stowing for certain specific purposes. Although some private firms have been stowing in the different coalfields for safety in the mines while aiming at maximum extraction, it is a fact that sand-stowing so far has been extended for safety only and not also for conservation. The scope of stowing, therefore, should include the conservation aspect as well.

The Jambad-Kajora and the Jharia fields are in urgent need of stowing in the immediate future, where $3\frac{1}{2}$ to 4 and 27 million tons respectively of sand will be required. The scope of stowing will further increase if and when underground gasification of coal is undertaken in this country.

As regards the sand in the rivers adjacent to the Raniganj and the Jharia coalfields, it has been estimated that in the former area 990 million tons of sand containing about 15 to 20% of clay are available, while in the latter some 140 million tons of sand together with 25 to 30 million tons of older alluvium are available. The quantity is considered to be sufficient for the Raniganj coalfield, but the amount is inadequate to meet the probable future requirements of the Jharia field. Hence there is the necessity for extensive research for finding out new material for stowing.

The question of the annual replenishment of sand will be more complicated after dams have been built across the Damodar and its tributaries, when practically all the sand and silt will be deposited in the reservoirs and they will have to be removed by dredging. The afforestation programme of the Damodar Valley Corporation in the catchment of the Damodar river system may further reduce the annual replenishment of sand in the rivers.

INTRODUCTION

The Damodar Valley has been referred to as the Ruhr of India. The coalfields in this valley are responsible for about 80% of the total output of coal in India valued at 35 crores of rupees. For the efficient and maximum extraction of coal, sand-stowing is becoming more and more important in the coalfields in the Damodar Valley and in other areas. Sand-stowing is the process of filling up with sand of the space which was previously occupied by coal but subsequently emptied by the extraction of the latter. This was practised for the first time in the United States of America about the year 1892 with the object of protecting buildings on the surface and also the surface itself. In India the introduction of this process is comparatively new; it was first tried at Ballarpur in Madhya Pradesh about 1914 and subsequently introduced in the Jharia coalfield about 1919. Since then it has gained further popularity and the method has since been introduced in certain parts of the Raniganj and Bokaro coalfields in Bengal and Bihar and also in other coalfields in India. At present there is one other country, viz. Poland, which practises hydraulic stowing comparable to that in India and where for the present production of 70 million tons of coal, 11 million cubic metres of sand are stowed; the respective quantities for India being 31 million tons of coal and 38 lakhs tons of sand in 1949.

ADVANTAGES AND DISADVANTAGES OF STOWING

By recourse to stowing most of the dangers arising from subsidences, fires, premature collapses, explosions and flooding in coal mines can be avoided and also

by this the maximum percentage of recovery can be effected without any loss of unworked coal and in a general way the working conditions for miners are made more safe. Stowing also helps in the concentration of operations in connection with winning of coal, improves ventilation and makes haulage and traffic underground much safer. As against the above advantages the main objection to stowing is economic—it involves a cost which goes to increase the cost of production of coal, thus putting the mines that take recourse to stowing in a disadvantageous position *vis-a-vis* those who do not stow. In some cases, however, when stowing becomes absolutely necessary for a particular colliery for extracting coal it has no other alternative but to take to it and run into additional financial commitments.

COST OF STOWING

The cost of stowing varies but usually it is not cheap; in fact it constitutes the major portion per ton of coal raised. Mr. L. J. Barracrough (1950), mentions that although longwall working has been resorted to in India for stowing to avoid disastrous major 'bumps', it has no direct advantage over normal pillar extraction with complete stowing in so far as cost is concerned. Mr. Barracrough gives comparative figures of cost for the two systems which are Re. 1-5-8 and Re. 0-9-4 for two collieries 1,460 feet and 916 feet deep and carrying out the longwall working and pillar extraction respectively. He further mentions that, 'The extra cost for longwall work mainly is due to the number of extra men required for erecting and removing boxings and the cost of boxing materials.' Mr. A. B. Guha (1950), who was in charge of a group of collieries in Madhya Pradesh during the last War, where hydraulic stowing in longwall faces was carried out, has pointed out that the cost thereof was comparatively lower. It is therefore necessary to ascertain whether reduction is possible 'of this particular item, otherwise winning of coal by longwall methods and specially by sand-stowing may not be remunerative and colliery owners may hesitate to adopt longwall system of winning coal by hydraulic stowing'.

METHOD OF STOWING

Stowing can be done by hand; it can also be pneumatic and hydraulic. Hand-packing is a dry and slow process which is comparatively less costly as it does not require any water used for the work to be pumped out. This, however, can be practised only in small operations. Pneumatic stowing is also a dry process in which compressed air forces the stowing material into the required position. This is rather expensive and is only suitable for deep mines from which the pumping of underground water involves some high cost and in cases where there is no adequate supply of water for hydraulic stowing. In India the hydraulic stowing is most suitable for the simple reason that there are apparently sufficient supplies of sand and water in the rivers in the neighbourhood of most of the coalfields where the inclination of the seams is generally suitable for the process.

STOWING MATERIAL

It goes without saying that sand is the most suitable material for sand-stowing wherefrom the name has been derived. Some other materials such as ash and cinder from boulders, rock debris and surface soil (suitably crushed wherever necessary) occurring in the neighbourhood of the stowing places are also conveniently used for stowing. Sand, for stowing, does not require to be crushed and it has the further advantage that it is subject to very little compression after settling.

CONTRIBUTIONS TO STOWING

The Mining, Geological and Metallurgical Institute of India has taken a keen interest in the matter of sand-stowing and it is responsible for some of its members

producing fine papers on the subject. One of the latest is a valuable contribution to the subject of hydraulic stowing by its President, Mr. L. J. Barraclough (1950). Some of the company members of the Institute, such as, the Bengal Coal Co., Messrs. MacNeill & Barry Ltd., Bird & Co., Tata Iron & Steel Co., etc., have been responsible for doing a lot of stowing in their collieries and thereby also helping in the research on the subject.

LEGISLATION FOR STOWING

The Coal Mining Committee of 1937 recommended for the creation of a Statutory Authority for controlling stowing operations in the collieries. But the Government of India set up, instead, the Coal Mines Stowing Board. The Coal Mines Safety (Stowing) Act, which was concerned only with the safety in coal mines, came into operation from the 27th May, 1939, and had been applicable to the whole of British India except Assam and the Punjab. The objects of the Act are as follows:—

- (i) To make further provision for safety in coal mines, by taking measures to facilitate or require therein the carrying out of the operations known as stowing; and
- (ii) to provide for the creation of a Fund for the assistance of such operation.

The Chief Inspector of Mines in India or an Inspector of Mines under him, according to the Act, has got powers to order the owner, agent or manager of a colliery to execute such protective measures, including stowing as the Chief Inspector of Mines may consider necessary if the former is of opinion that:—

- (a) the extraction or reduction of pillars in any part of the mine is likely to cause the crushing of pillars or the premature collapse of any part of the workings or otherwise endanger human life or the mine, or
- (b) adequate provision against the outbreak of fire or flooding has not been made by providing for the sealing off and isolation of any part of the mine or for restricting the area that might be affected by fire or flooding, as the case may be.

As regards the creation of a Fund, the Government of India had fixed annas two per ton as cess on coal and soft coke and annas three per ton on hard coke from the 1st December, 1939. These cesses have, subsequently, been increased by 50 per cent with effect from the 1st May, 1947. The collection is made by the Railway Administration and the total amount, after deducting the collection charges, is handed over to the Stowing Board.

RULES FOR GRANT OF ASSISTANCE

The Stowing Board has formulated the principles which are to govern the grant of assistance from the Stowing Fund to the owners, agents or managers of collieries and rules have been framed under the Coal Mines Safety (Stowing) Act. According to the rules, the Stowing Board has authority to grant assistance for the following purposes:—

- (a) For stowing or other protective measures which are required to be undertaken by an order issued by the Chief Inspector of Mines in India under sub-section (3) of Section 9 of the Act;
- (b) For any protective measures which in the opinion of the Board are essential for the effective prevention of the spread of fire to, or the inundation by water of, any coal mine from an area adjacent to it;
- (c) For stowing operations voluntarily undertaken by the owner, agent or manager of the mine in the interests of safety; and
- (d) For research connected with safety in mines.

As regards protective works under (a), a number of orders have been issued and important protective works, especially in the Jharia and the Karijore fire areas, have been undertaken for some time past and are still being continued as provided for under (b). Regarding voluntary stowing as provided under (c), the greatest activity has been on record in this connection.

ORDER OF PRIORITY FOR GIVING ASSISTANCE

The following order of priority is kept in view when applications asking for assistance for voluntary stowing are considered by a Standing Advisory Committee appointed by the Stowing Board:—

- (a) Anticipated immediate danger to themselves and to other collieries.
- (b) Anticipated major danger to their workers.
- (c) Lesser degree of urgency under the above heads.
- (d) Abnormal working conditions due to geological features involving added risks.
- (e) Working under fire areas or under water (*vide* Regulations 67-E, 72-B or 75 of the Indian Coal Mines Regulations).

STOWING FOR CONSERVATION OF COAL

It will appear, therefore, that the scope of the Act is confined to stowing for safety only and not for conservation. In view of the heavy losses of coal due to fire and collapses it is felt that time has come for enforcing stowing for conservation also and in view of the rather limited reserves of good metallurgical coal and of the proposed expansion in the iron and steel industry in the country, compulsory stowing appears to be essential. Mr. Treharne Roes, as early as 1919, recommended the introduction of hydraulic stowing in the Jharia and Raniganj coalfields and the Coal Committee of 1920, which considered his report, came to the conclusion that no improvement in the prevailing wasteful methods could be expected without State interference and that sand-stowing should be made compulsory within certain limits with provision for compensation. The Coal Mining Committee of 1937, which was primarily concerned, under its terms of reference, with safety in mines, while considering the importance of conservation of the country's resources of good quality coals realized that stowing for safety in mines and preservation of the admittedly limited resources of coal were essential. The Indian Coalfield's Committee, 1946, stressed the necessity for extending stowing for conservation also. But so far the Government of India have thought fit to extend stowing for safety only and not also for conservation.

The Metallurgical Coal Conservation Committee of 1949 is believed to have also realized that the scope of stowing should include the conservation aspect as well. It is not known if the Government of India will introduce stowing also for conservation of at least the good quality coals.

UNDERGROUND GASIFICATION OF COAL AND STOWING

The scope of stowing will further increase, if and when underground gasification of coal is undertaken in this country. The first idea for underground gasification of coal occurred to Sir William Ramsay of Great Britain, where, as also in the United States, no effort was made to give a practical shape to it. The great Russian scientist, Mendeleef, independently advised the conversion of coal into gas in the coal seams and the Soviet Government in its turn took up the problem of underground gasification and preliminary work was started on an experimental basis in 1932. The development of the technique in U.S.S.R. has been dealt with in a recent paper by Dr. A. K. Shaha (1950). In India, no work so far has been done towards the underground gasification of coal, but here the requisite type of coals may be available.

This is, however, still in its infancy in Russia and we will have to await the development of requisite technique for satisfactory work. Underground gasification includes injection of air and steam through burning coal underground, whereby a mixed gas containing CO , CO_2 , H_2 , CH_4 , C_nH_m , N_2 , etc., is produced. To ensure that the injection of air and steam reaches the proper place, it is absolutely necessary that the void created by the burning of coal be properly filled up. This filling could be done by (i) natural fall of earth, (ii) pneumatic filling, and (iii) hydraulic stowing. It will be clear that hydraulic stowing does not require the introduction of steam as it serves the double purpose of sealing and steaming. Thus, if and when underground gasification of coal is undertaken in India, additional quantities of sand will also be required for filling up the space created by the burning of coal underground.

RESERVES OF SAND

It has already been mentioned in a general way that sand and water are available in sufficient quantities in the vicinity of the coalfields. It is now necessary to consider to what extent the stowing material will be available and also to understand the economics of stowing. Mention has been made that such materials as ordinary earth, broken stone excavated from quarries and such incombustible substance as ash from boilers have been used in some cases mainly for stabilizing underground workings where sand is not readily available; but the available quantities of such material are very limited. India has been very fortunate in so far as the availability of sand is concerned from her rivers, especially from those in the vicinity of the two main coalfields, viz. the Jharia and the Raniganj coalfields. As regards the quantities readily available in the neighbourhood of the two above-mentioned coalfields, the Indian Coalfields' Committee of 1946, considered the position as satisfactory and stated (on page 92) in its report that—

'On the whole, the available evidence points clearly to the existence of adequate sand deposits in the three rivers (Damodar, Barakar and Ajay). But the position has been complicated by the plans for the construction of dams across the Damodar for flood control and irrigation and much genuine concern has been felt about the prospects of sand replacement in the future.'

The quantities of sand available from the present bed of the Damodar river within the Jharia coalfield were estimated by Sir Cyril Fox (1930) on a very limited data. Messrs. Bird & Co., who hold the lease for sand in the Damodar adjacent to the Jharia coalfield, have undertaken sand-drilling operations in the river from Kalhajhor ($23^\circ 40\frac{1}{2}' : 86^\circ 35\frac{1}{2}'$) up to Totengabad ($23^\circ 43' : 86^\circ 20\frac{1}{2}'$) and have estimated that some 140 million tons of river sand occur at present as the fixed deposit of the river in the Jharia field. In addition, the older alluvium of the Damodar in the above area, which might also be a suitable material for stowing, was estimated by Sir Cyril Fox at 25 to 30 million tons.

The Coal Mines Stowing Board has for some time under consideration a scheme for the supply of sand for stowing at collieries in the Jambad-Kajora and Toposi areas in the eastern part of the Raniganj coalfield from the Damodar river at Shrirampur ($24^\circ 34' : 87^\circ 12\frac{1}{2}'$) and from the Ajay river near Ramnagar ($23^\circ 44' : 87^\circ 15\frac{1}{2}'$) using aerial ropeways. Advice was sought from the Geological Survey of India regarding the quantity of river sand available in the two areas. In furtherance of the above programme and in connection with the general sand-stowing programme for conservation of coal and the safety of mines in the Bengal and Bihar coalfields, the Geological Survey of India, in order to arrive at fairly definite estimates of river sand, carried out extensive sand drilling operations by making drill-holes at suitable intervals in the following areas:—

- (i) In the Damodar river from near Shrirampur ($24^\circ 34' : 87^\circ 12\frac{1}{2}'$) upstream to its junction with the Barakar river,

- (ii) in the Barakar river from its junction with the Damodar upstream to near the proposed Maithon dam site, and
 (iii) in the Ajay river from the north-western end of the trans-Ajay field near Pariarpur ($23^{\circ} 50' : 87^{\circ} 03'$) to north of Madhaipur ($23^{\circ} 43' : 87^{\circ} 21\frac{1}{2}'$).

The holes were put down at intervals of 1,000 feet both along and across the river beds and the total number of holes was 321. The results obtained, by the Geological Survey, are given below in a summarized form:—

Reserves of Sand in the Damodar, Barakar and Ajay Rivers within the Raniganj Coalfield

River	Area	Average thickness of sand	Total in million tons
(A) Damodar river ..	Baska ($23^{\circ} 34' : 87^{\circ} 10\frac{1}{2}'$) to Pinjrapole ($23^{\circ} 33' : 87^{\circ} 14'$).	29½ ft.	70 (including 10% clay).
Ditto ..	Baska to junction of Damodar and Barakar.	32½ ft.	510 (including 10% clay).
(B) Barakar river ..	Junction of Barakar and Damodar to Maithon ($23^{\circ} 47' : 86^{\circ} 49'$).	42½ ft.	120 (including 20% clay).
(C) Ajay river ..	Ramnagar ($23^{\circ} 44' : 87^{\circ} 15\frac{1}{2}'$) to Chhatrishganda ($23^{\circ} 44' : 87^{\circ} 13\frac{1}{2}'$).	8 ft. 19 ft.	3 } (including 40% clay). 17 }
Ditto ..	Pariarpur ($23^{\circ} 50' : 87^{\circ} 03'$) to Chhatrishganda and Ramnagar to Madhaipur ($23^{\circ} 43' : 87^{\circ} 21\frac{1}{2}'$).	35½ ft.	270 (including 20% clay).
Total .. ..		....	990 million tons.

Sand in some quantities is also available in the Damodar, Bokaro and Konar rivers within the Bokaro coalfield and although the actual quantity has not yet been estimated it is believed that it may not exceed a quarter of that in the Damodar river in the Jharla coalfield. Further up the Damodar river, in the Karanpura field, the bed of the river is still more rocky and the accumulation of sand is very scanty.

REPLENISHMENT OF SAND

As regards the questions of availability of water and the annual replenishment of sand in the rivers, Dr. Auden is dealing separately on them. In the Jharla coalfield, Dr. Gee (1947) mentions that, even if we 'allow a total of about 200 million tons of readily available stowing material as the fixed deposit, it is quite apparent that, in order to provide an annual quantity of even 20 million tons per annum to meet the needs of the Jharla coal industry, a very large annual replenishment of river-sand during the flood-period of the monsoon is essential, otherwise supplies will be depleted within a short period of years.' The present rate of annual replenishment of the sand is not known with any degree of accuracy, but it is said to be of the order of 11 million tons. When the dams are built across the Damodar and its tributaries most of the sand, if not the whole of it, will be deposited in the reservoirs from where the sand and silt will have to be removed by dredging and distributed to the collieries for stowing.

I may also make a brief mention here of the proposed afforestation programme of the Damodar Valley Corporation in the catchment of the Damodar river system which may further reduce the annual replenishment of sand in the rivers. Afforestation is one of the measures which has been found useful in combating soil erosion. In the catchment of the Damodar river system it has been observed that 60-70% of the area has a cover of subsoil and decomposed rock varying from 0 to 6 inches, while the remaining 30-40% has a soil cover varying from 6 inches to 3 feet and above. In the former area afforestation will aid reclamation while in the latter it will help soil conservation.

PLANNING AND RESEARCH

Mr. L. J. Barraclough (1950), in responding to the toast at the Annual Dinner of the Mining, Geological and Metallurgical Institute of India in December, 1949, observed as follows:—

‘The question of planning with regard to sand-stowing occupies our minds. The Jambad-Kajora field which produces high volatile coals is now in urgent need of stowing and from 3½ to 4 million tons of sand will be required yearly. For the Jharia field the quantity of sand will increase to 27 million tons per year starting in 1955. It is of great urgency that complete schemes be drawn up now for stowing in the Raniganj and the Jharia fields.’

In the discussions following a very recent paper of Mr. R. R. Khanna (1950), it has been evident that certain mechanical difficulties are being encountered in the matter of stowing. These require proper attention from competent people who are in a position to solve them.

Also, although the quantity of available sand in the rivers traversing the Raniganj field may be considered to be sufficient for stowing purposes in this area, the sand together with the quantity of older alluvium in the Damodar river in the Jharia field is not considered to be enough to meet the probable future requirements of this field and also there may not be adequate quantities of sand readily available in the rivers in close proximity to other coalfields, where stowing operations are to continue or are likely to be introduced in future.

It has been suggested that the ash from the Bokaro Thermal Plant may be used for stowing. Although the material could be used with advantage locally in the Bokaro coalfield, it is doubtful whether it could be transported cheaply to the Jharia coalfield, wherein exist most of the good quality caking coals of India which have to be stowed for their efficient and maximum extraction.

It is, therefore, felt that there is now the urgent necessity for planning for stowing and for extensive research not only in the development of the technical methods, but also for finding out new materials suitable for stowing, which could be made available to the collieries at a reasonably small cost.

ACKNOWLEDGMENTS

I have to thank the Committee organizing the symposium and particularly my Director, Dr. W. D. West, for providing me with an opportunity to contribute this paper and to Dr. P. K. Ghosh, for giving me valuable suggestions in its preparation.

BIBLIOGRAPHY

- Barraclough, L. J. (1950). Hydraulic Stowing In India—A Record of General Observations. *Trans. Min. Geol. Met. Inst. Ind.*, **45**, No. 4 (In press).
 ——— (1950). Post-Dinner Speech, December, 1949. *Trans. Min. Geol. Met. Inst. Ind.*, **46**, No. 1 (In press).
 Fox, C. S. (1930). The Jharia Field. *Mem. Geol. Surv. Ind.*, **56**, 107-108.
 Gee, E. R. (1947). India's Reserves of Coal and River-Sand. *Indian Minerals*, **1**, No. 2, 78.

- Guha, A. B. (1950). Discussion of L. J. Barraclough's paper on Hydraulic Stowing in India—A Record of General Observations. *Trans. Min. Geol. Met. Instt. Ind.*, **45**, No. 4. (In press).
- Khanra, R. R. (1950). Hydraulic Stowing in India—Preliminary Investigations of Factors Limiting Quantities of Sand Stowed per Hour. *Trans. Min. Geol. Met. Instt. Ind.* (In press).
- Shaha, A. K. (1950). Underground Gasification of Coal. *Manufacturer*, **1**, No. 10, 11-17.

DISCUSSION

MR. P. K. GHOSH.—I would like to take this opportunity of thanking the author for his excellent paper giving so much information as regards the availability of sand in the rivers adjoining the coalfields of Bengal and Bihar.

Though it has been considered until recent years that the sands required for stowing in the Raniganj and Jharia coalfields are more or less sufficient for the purpose of safety in the mines, with the dams now to be built across the Damodar and its tributaries, the annual replenishment of sands in the rivers may not be sufficient for future needs. Practically all the sand and silt will be deposited in the reservoirs, and these will have to be removed by dredging. This will mean extra cost. It is now time, therefore, that we should think also of other stowing materials besides sand. There will be a good amount of washery refuse (when coal washing plants are installed), boiler ash, screening plant rejections, shales, surface soil, sub-soil, etc., ready available within the easy reach of mines. These materials can at least supplement sand as stowing materials. As regards the substituted stowing materials, an interesting paper was written by Dr. S. K. Roy in 1938 (*Trans. Min. Geol. Instt. Ind.*, Vol. 33, Pt. 4, pp. 443-454). Dr. Roy has mentioned that this 'muttee' (including shale, soil, sub-soil, ash, etc.) alone may be able to supply stowing materials for the important mines (raising 1st class coal), situated in Sheets 3, 7 and 8 of the Jharia coalfield. It may be worth while investigating these materials in the rest of the Jharia coalfield, and in other coalfields as well. Some of the collieries in Jharia and other fields have already been utilizing boiler ash as stowing material.

It is time that we should also consider the possibility of adopting different methods of stowing, such as pneumatic or mechanical stowing, in addition to hydraulic stowing. Perhaps, with pneumatic stowers, ordinary 'muttee' along with substitutes may be used. For the collieries which are fortunate in having adequate sand supplies, hydraulic stowing may be best suited; but in the case of collieries miles away from sand supplies and with plenty of other materials available, different methods of stowing may be adopted. Mr. J. Thomas published an excellent paper on this aspect of stowing in 1939 (*Trans. Min. Geol. Instt. Ind.*, Vol. 35, Pt. 1, pp. 51-128).

MR. A. B. DUTT replying to Mr. P. K. Ghosh said that, the question of sand-stowing is not so acute in any other area as it is in the Jharia coalfield, where, according to recent estimates, there are nearly 1,500 million tons of good quality coking coals, which require to be stowed. Taking the maximum quantity of stowing material readily available in this coalfield to be about 200 million tons and assuming 27 million tons or, say, roughly 25 million tons of sand as the quantity required per year, it is evident that the supplies will be exhausted within a short time unless there is a very large annual replenishment of river-sand during the monsoon floods. The replenishment, however, will not take place to the same extent with the dams built across the rivers in the Damodar river systems.

Regarding the use of the ash from the Bokaro Thermal Plant for stowing, it may be said, that although it could be used with advantage locally in the Bokaro coalfield, it is doubtful whether it can be transported cheaply to the Jharia field. That means the cost of stowing material and necessarily that of stowing will increase further, thus upsetting the price-structure of coal. Moreover, the quantity will hardly be over 1 million tons per year.

FISHERIES CONSERVATION AND DEVELOPMENT

By SUNDER LAL HORA, D.Sc., F.R.S.E., C.M.Z.S., F.R.A.S.B., F.N.I., Director,
Zoological Survey of India, Calcutta.

SUMMARY

The author regrets that in assessing multiple water use, fishery interests have been neglected in the past and fish experts have often not had the opportunity of representation on planning boards and administrative agencies concerned with water use. In the U.S.A., where techniques of the multiple water use are most advanced, it is illegal to ignore fishery interests and in no case could they be sacrificed, except when any proposed water development exceeds in public value the fisheries resources. A plea is made for enactment of a similar legislative measure in India.

It is impressed that in undertaking any development measure, river should be treated as a physical unit and the planning should not be limited to individual projects. Further, it is pointed out that each river has its individuality and, therefore, no rules of thumb can apply to all projects.

In dealing with preconstruction fishery investigations, attention is invited to observational studies, such as fish and fishery surveys, biology of fishes of economic importance and hydrostatic and hydrodynamics of the river, and analytical studies, such as hydrology of the river in relation to the bionomics of the species to be protected and developed and correlation of the engineering project with the requirements of fish.

Programmes for the culture of fishes in impoundments and the protection of the runs of migratory fishes through dams are outlined.

It is emphasized that the development of river basins should be planned for the welfare of man but not for the exploitation only of a certain set of their resources.

CONTENTS

	Page
Introduction	521
American Fishery Policy and its Lesson for India	522
River as a Physical Unit for Development	523
Pre-Construction Fishery Investigations	523
Fish Culture Programme	524
Protection for Migratory Fishes	524
Conclusion	525
References	525

INTRODUCTION

'Multiple water use now exists, but the use is seldom as wise or as efficacious as it should be. Fishery interests in particular have been neglected, and fish experts have often not had, or have not fully taken, the opportunity of representation on planning boards and administrative agencies concerned with water use.' *Carl L. Hubbs.*

The above remarks were made by Professor Carl L. Hubbs (1941) as Chairman of the Symposium on 'The Place of Fish Production in a Program of Multiple Water Use' organized by the American Fisheries Society about a decade ago. If such is the state of affairs in an advanced country like U.S.A., the neglect shown to fisheries interests in India is far worse. In a recent article, I (1949) narrated Indian experience regarding protection of fish and wildlife in reference to hydro-power and other water uses and showed therein that a majority of fishways hitherto constructed in India, evidently without any knowledge of the nautical properties of Indian migratory fishes, have proved ineffective. The programme of setting up hatcheries for overcoming the baneful effect of dams on the migratory movements of the Indian Shad, *Hilsa ilisha* (Hamilton), has also failed. It is high time, therefore, that the country

should seriously consider anew a programme of fisheries conservation and development with reference to multi-purpose river projects, a number of which are already in an advanced stage of execution.

It is now a fashion in India to imitate the U.S.A. programmes of multiple water use but I think very little attention is paid to the basic requirements of the Americans and their economy on which these programmes are undoubtedly based. During my visit to the U.S.A. last year, I availed myself of the opportunity to discuss fishery problems with American experts, always keeping in view India's national economy, and at Seattle it was my good fortune to come in contact with Mr. H. B. Holmes of the Fish and Wildlife Service who, as Aquatic Biologist with U.S. Engineers, has been in charge of the Fish Protection at the Bonneville Dam. Two days' discussion with Mr. Holmes on the conservation and development of fisheries in relation to multi-purpose river projects has enabled me to draw up a general programme, which can be modified to suit local conditions of any specified project. I have also embodied in this note some of the views expressed at the Water Section Meeting of the United Nations Scientific Conference on the Conservation and Utilization of Resources on Hydro-Power and other Water Uses relevant to Indian conditions.

AMERICAN FISHERY POLICY AND ITS LESSON FOR INDIA

It is perhaps pertinent to quote here two sections of the American Fishery Policy pertaining to multiple water use, as these will give us the background of fish protection work in the U.S.A. Section II (1) reads:

'The federal, dominion, state, provincial, and regional planning boards should consider the fishery resources as a very important element of national wealth and not as a minor incident in the development of power, flood control, drainage, irrigation, reclamation, and recreational projects, as has been done in the past. The planning boards should recognize wherever possible the principle of prior right for the fisheries. Only when a proposed water development exceeds in public value the fisheries resources, should the latter be sacrificed, in which case the fishery interests should be compensated fully for their losses. The fisheries should be given equality of representation on all planning agencies at all times and should be represented by qualified persons from the state, provincial, and federal agencies involved.'

The other section pertinent to our discussion reads:

'Since soil erosion, reforestation, drainage, flood control, water restoration, and impoundment of waters are now recognized as tremendously important factors in fish production, the closest contact should be maintained between fishery officials and the agencies responsible for these various activities.'

In India, there are hardly any effective fishery conservation and development laws which could enforce proper attention being paid to fishery resources in a programme of multiple water use. Our first need would, therefore, appear to be the enactment of suitable laws for fish protection. Now that we have a National Planning Commission as a permanent body in the Government of India, it is hoped that some suitable action may be taken to recognize prior right for the fisheries in undertaking multi-purpose river projects. India at present seems to be suffering from the disease of hydromania in its most virulent form which has made it blind to practically all other interests, except so many kilowatt hours going to waste or so many millions of acres of land lying barren for want of irrigation facilities. We should be able to see other values in a stream well in advance of engineering projects. In the past, one feels that in the planning and construction of irrigation and other reservoirs aquatic values have been ignored in almost every instance. Will this attitude persist even under the national government?

RIVER AS A PHYSICAL UNIT FOR DEVELOPMENT

In planning a multi-purpose river project, attention is generally paid to a section of the river and not to the effects of the projects on the river as a whole. Such a procedure is against national interests. At the United Nations Scientific Conference, Mr. Leland Olds rightly observed that the entire river should be 'looked upon as the physical unit to be developed rather than limiting the planning to individual projects'. Though he was dealing with hydro-power and conservation, his statement is particularly true in regard to the fishery resources. The fisheries are greatly influenced by fluctuations in water level, volume of water flowing down a stream, obstructions in the course of waterways, etc. etc., and it is essential, therefore, that the effect of any protective work should be appraised for all sections of the river. Let us take, for example, the Ganges to illustrate this point. The Indian Shad ascends the river from the foreshore and estuaries when the river is flooded during the monsoon season. If the waters flowing into it are controlled in the upper and middle reaches, naturally the intensity of flooding in the estuaries will be greatly diminished with the probable result that the *Hilsa* fishery of the entire river system will be adversely effected. Even the productive estuarine fisheries, dependent on low salinity, will be adversely effected. It is imperative, therefore, that in considering fishery interests, the economics of the fishery of the entire river system should be taken into consideration, and that the needs within the entire river basin for the various water uses should be appraised in terms of their relation to and effect upon one another.

It is also necessary to emphasize here that each river and each project have their individualities, and must be thoroughly investigated from all aspects before any measures for the conservation and development of fisheries can be adopted. Though the results of various projects can serve as guides for conducting investigations on new projects, there can be no rules of thumb for solving fishery problems of different river basins.

PRE-CONSTRUCTION FISHERY INVESTIGATIONS

As soon as it is decided to utilize a water resource, the following fishery investigations should be started even before any engineering estimates are undertaken. The object of these investigations will be to appraise the present value of the river basin in the national economy. It is hardly fair to tell the fishery biologist: 'Here is a dam; now you do the best you can with it,' for fish protection is not such a simple matter.

Observational Investigations.—At the very outset it is necessary to know the fish fauna of the river basin and the value of the fishery based on the species of economic importance. The programme would, therefore, include:

1. *Fish and Fishery Surveys*
 - (a) Collection and determination of the fish fauna.
 - (b) Economic Fishery Surveys to indicate the production of various species, men employed in the industry, the types of nets and boats used, etc, etc.
2. *Biology of fishes of Economic Importance*
 - (a) Life-history and Bionomics.
 - (b) Migratory movements and their causes.
3. *Hydrostatics and Hydrodynamics*
 - (a) Movement intensities or the Physics of Movements.
 - (b) Flow pattern of the water basin concerned.

Analytical Data.—When the above observational data have been collected, they will then have to be equated against similar observational data collected by the Engineering Section. The programme in this phase will include such items as:

1. Hydrology of the water basin and its correlation with the bionomics of the species to be protected and developed.
2. A study of the Engineering Project and to determine its effect on the requirements of fish.
3. Analysis of the fishery and the engineering requirements for co-ordinating the two programmes.

When the observational and analytical phases have been carefully gone through, then the Engineering Project should be formulated in the light of fishery investigations. The problems that may have to be tackled may be of different types in different basins. For instance, the problem may be of Fish Culture, as is the case of the Pipri Dam Reservoir (Hora, 1948) on the Rihand River of the Mirzapur District (U.P.) or the Reservoirs to be constructed in connection with the Damodar Valley Project. The problem may be of the Movements of Migratory Fishes, or combination of both Fish Culture and Provision of Facilities for Migratory Fishes.

FISH CULTURE PROGRAMME

For fish culture, you have to consider the availability of fish seed or seedlings for stocking. If we have already species that breed in impounded waters, then the main question will be to provide them with suitable breeding grounds in the reservoir itself by the proper adjustment of water level during their breeding season. If the commercially important species, such as the Indian Carp, do not breed in impounded waters and seedlings have to be stocked every year, the question of setting up artificial breeding grounds, hatcheries and nurseries will have to be considered. It is quite possible that local species may not be found suitable for commercial exploitation and exotic or semi-exotic species may have to be introduced. This seems likely in the case of the Kosi Dam Project. This will involve a great deal of experimentation and research before suitable measures can be adopted on an extensive scale. I do not wish to go into the details of fish cultural practices here but attention must be invited to the difficulties that will have to be encountered in harvesting the crop in very deep waters over an uneven bottom.

PROTECTION FOR MIGRATORY FISHES

The problem of affording protection to migratory fishes is very difficult indeed and here the question of relative economics comes to the fore front. The measures that have been adopted for fish protection comprise:

1. Construction of fishways in dams.
2. Construction of fish locks for the transfer of fish from the lower level of the stream below the dam to the water level of the reservoir above the dam.
3. Transference of the fish to other streams having suitable runs and breeding grounds.
4. Improvement of spawning grounds below the dams in the main channel or the side streams.
5. Artificial spawning and rearing below the obstruction for maintaining runs.

As pointed out in the beginning, Nos. 1 and 5 have already been tried in India to a certain extent and have, in the past, proved ineffective. This is a field in which an integrated and thoroughly co-ordinated research programme between the engineers and fishery biologists can lead to very profitable results. If the hydraulic engineers

and pisciculturists were to co-operate from the very outset of the project, it could be possible to eliminate the harmful effects on fisheries of building dams. In fact, possibilities are that development measures may even improve the original condition of the fisheries.

CONCLUSION

It is perhaps necessary to emphasize in conclusion that the development of river basins must be planned for the welfare of man and not only for the exploitation of a certain set of their resources. Any kind of exploitation of their resources must take into consideration measures to protect fish and to ensure development of fisheries.

REFERENCES

- Hubbs, Carl L. (1941). The place of fish production in a program of multiple water use. *Trans. Amer. Fisheries Soc.*, **71**, 297.
 Hora, S. L. (1948). A very rough estimate of the probable fish production in the Pipri Dam Reservoir. *Journ. Central Board Irrigation*, **5**, pp. 405-406.
 Hora, S. L. (1949). Indian experience regarding protection of fish and wildlife in reference to hydro power and other water uses. *Journ. Central Board Irrigation*, **6**, pp. 18-21.

DISCUSSION

DR. T. J. JOB.—As I have had to be associated for some time past with the fish and fishery survey of the Damodar Valley Project, I may venture to offer a few words on the paper on 'Fishery Conservation and Development' by Dr. Hora, with some reflections on Mr. Sain's paper on the 'Principles of Planning'.

A project to be really multi-purpose in nature, should aim at tapping all the utilizable potentials involved in it. While due emphasis has to be laid on the common accepted uses of water such as drinking, washing and navigation and on the important functions of dams such as flood control, irrigation and power generation, the exploitation of the aquatic food resources in the river systems deserves much more attention than has hitherto been bestowed on it, especially in the present food crisis. Rivers are the highways of inland fisheries, and several economic species of fish have their sojourn in the extensive feeding and breeding grounds in the river systems. The significance of the fishery resources in relation to dams has been very well expounded by Dr. Hora. Thanks to the repeated stress on this aspect laid in our country by Ichthyologists and fishery workers from the time of Sir Francis Day, some attention has now begun to be paid on the subject. It is gratifying to observe that the Damodar Valley Project has included in its programme some work on the conservation and development of the fisheries of the valley waters. Unfortunately, various snags and limitations of staff and equipment considerably delimit this new line of work in which not only biologists but also expert fishery engineers have to make concerted efforts.

For a rational exploitation of the fisheries of a river and its basin, one should not only know the details of its existing fish population, but also the possible effects of the project on the fishery, with due reference to the feeding, breeding and migratory habits, both long and short range of the fishes. Their vital correlation with the hydrology and hydromatics of the river system has to be understood. The reaction of the fish population to the topographical and hydrological changes which may be brought about by the project should be elucidated before the nature of a fish ladder, fish lift or other device, as also measures of conservancy and protective legislation could be decided. In order to utilize the fish cultural potentialities of the reservoirs to be formed and the tanks and ponds which may appear in the valley, the nearest fish seed sources should be ascertained and the most profitable combinations of compatible species should be stocked in the different types of waters, the productivity of which should be enhanced by proper aquatic manuring. These problems are to be tackled jointly by the fishery engineer and the fishery biologist.

Last evening, Mr. Kanwar Sain rightly stressed the need for 'Planning Ahead'. Indeed the fishery position of a river should be determined as Dr. Hora has pointed out long before the construction stage so that necessary provision for the fisheries could be duly incorporated in the project.

One point which has always struck me in the course of my experience with Public Works men is that irrigational, hydro-electric and fishery interests, if properly assessed and understood can be co-ordinated rationally with benefit to all the three and prejudice to none.

As in all aspects of a river project, in the fishery aspect also, each river system has to be studied individually and intensively. What may be true of one river may not apply to another, even though the basic fundamentals may be constant.

By treating each river system as a natural unit and working out the project thereof along a well integrated plan, India will be able to derive the maximum benefit out of the organic and inorganic resources of her numerous great rivers.

Dr. K. L. RAO.—Most of the dams we are building in India today are of heights greater than 100 ft. In such cases, it is difficult to provide fish ladders or passes or lifts. Even in United States of America and United Kingdom, no such provision is made in the high dams. Also in the case of Indian reservoirs, the fluctuation of maximum and minimum water levels is great so that no easy lift gate arrangements can be made for periodical opening as has been developed in recent dams in Scotland for passage of migratory fish. It is therefore necessary that Fisheries Departments should investigate thoroughly the characteristics of fish, etc. in a river across which a high dam is proposed and consider the possibilities of developing fish culture in the reservoir. No fish passes or ladders should be insisted upon unless it is proved that a big migratory fish movement will be destroyed.

Dr. S. L. HORA.—Replying to the remarks made by Dr. K. L. Rao and Mr. Kunwar Sain about the incapacity of fishery officers in India in rendering suitable advice in regard to the types of fish passes required in dams, Dr. Hora stated that this deficiency of knowledge was equally shared by fisheries biologists and the engineers. Whereas Fisheries in India received the patronage of the Central Government as late as 1944, the Engineers had this patronage for more than a century. It was more regrettable, therefore, that in their Research Institutes, the Engineers paid no attention to the requirements of the fish in connection with the construction of dams. What we need in India are Fisheries Engineers for a correct appraisal of the requirement of fisheries and of engineering designs. Such persons can more easily be trained in the Irrigation and River Physics Institutes in the country and not in Fisheries Research Institutes. Dr. Hora, therefore, advocated the need of co-ordinated and integrated research by fishery biologists and engineers.

When Administrative Officers can be put in charge of fisheries in the States, it is really too much to expect any suitable technical advice from them. Dr. K. L. Rao should have referred his problems to persons like Dr. B. Sundara Raj, who had already investigated the fisheries problems of the Mettur Dam.

Mr. H. B. HOLMES (in correspondence): An attitude prevails both in the U.S.A. and India of overemphasizing the need or desire to have fundamental data relating to the swimming ability and other reactions of the fishes with which we are concerned in the design of fishways. I agree that it is well to have such information and that we should be working toward obtaining it. On the other hand, the absence of such information should not interfere with or take the place of application of fish protection upon the basis of present knowledge. It is not necessary that a fishway be constructed to provide conditions that are just within the limits of the ability of the fish. It usually is permissible to design a fishway with standards of velocity and other conditions that leave no question of the ability of the fish to pass up it.

Dr. S. L. HORA.—When we proposed to the engineers in 1941 that fisheries should be adequately protected, they turned on us and required data about the swimming ability and other requirements of fishes to be supplied to them before they could design fish passes. Accordingly, Indian Council of Agricultural Research sanctioned in 1946 a scheme for investigation into the bionomics of Indian Migratory Fishes with a view to standardize designs for fish passes for a period of two years. Owing to political changes, much work could not be done under the scheme and so the position remains more or less what it has been. In the discussion today engineers have again blamed fisheries biologists for lack of data about the requirements of fishes and my only excuse has been that fishery science in India is yet in its infancy and that engineers should have studied this matter in their River Research Institutes.

Against the background of Mr. H. B. Holmes' remark that 'It usually is permissible to design a fishway with standards of velocity and other conditions that leave no question of the ability of the fish to pass up it,' it should now be possible to rebut the usual charges levelled against fishery biologists by the engineers.

SHRI D. V. JOGLEKAR. (in correspondence) : I agree with most of the views given by Dr. Hora but certain points need further clarification.

With reference to Fish Culture in reservoirs, Dr. Hora has stated: *If we have already species that breed in impounded waters, then the main question will be to provide them with suitable breeding grounds in the reservoir itself by the proper adjustment of water level during their breeding season.*

I would like to know the requirements of water levels for proper fish culture. It will then be possible to see whether these are conveniently in conformity of water levels for irrigation and power purposes.

Dr. Hora has also stated: *I do not wish to go into the details of fish culture practices here but attention must be invited to the difficulties that will have to be encountered in harvesting the crop in very deep waters over an uneven bottom.*

In almost all cases the bottom will be uneven and the waters will be deep and this raises an important issue, viz. the provision of fishways in dams and the construction of fish-locks for the transfer of fish from the lower level below the dam to the water level of the reservoir above the dam. Fish passes will not be possible in cases of very high dams. Fish-locks can be designed

for dams 100' to 200' high and for very low dams fishways are feasible. Is there any data to give the relation between the height of the dam and the various types of fishways?

DR. HORA.—Adjustment of water levels in the reservoirs will in each case be different according to the breeding habits of the species concerned, as the same species of fish are not found all over India. It is absolutely true that adjustment of water levels will have to be correlated with the needs of water for irrigation and power purposes.

The second point deals with only the catching of fish (cropping) in deep waters over an uneven bottom. The bottom nets cannot be used and our ordinary methods may prove futile in these reservoirs. Thus there is need to undertake capture research. The question of fishways is not raised in this case. Personally, I am now of the opinion that for most of our dams, fishways are not necessary.

SRI V. GANESH IYER (in correspondence): I am in agreement with Sri Hora's recommendation. The idea of preservation of fish and wild life is coming up prominently for consideration only in recent times. I am sure future designers of reservoir construction will give full consideration to this subject and you may hear more of it hereafter.

It is being increasingly recognized that planning and construction of engineering projects to serve more than one purpose will enable better conservation and utilization of national resources. Construction of large dams and reservoirs so as to make the streams navigable where they are not, to generate electricity to run factories and to irrigate vast areas of land are, no doubt, impressive features of multi-purpose projects. There are, however, other features which are equally important, if not so impressive. Conservation of fish and wild life is one such feature.

In his note Dr. Sunder Lal Hora lays emphasis on the fishery interests. Equal importance should be paid to the conservation of all species of wild life. The requirements of any particular species of wild life are comparatively simple consisting of handful of essential foods, an assured water supply and safe refuge and cover of vegetation of a reasonable quantity, say about 5% of the storage for wild life in any scheme of water conservation may safely be considered an entirely legitimate use.

Conversion from river to reservoir conditions following impounding of water will greatly change environmental conditions for fish and certain species of wild life. It creates both new problems for the perpetuation of these resources and new opportunities for their development. As for any engineering feature, extensive investigations should therefore be conducted to collect factual information essential to the solution of problems and to the development of opportunities for the full utilization of these resources.

A team of experienced biologists should be employed to make preimpoundment observations to determine the changes from the river to reservoir habitat. Investigations should include technical studies of water conditions, surveys of the extent, size, distribution and composition of fish populations, studies of their life histories, food supply, rate of growth, spawning and adaptation to the new environment.

The data so collected should then be correlated with other investigations of water storage and reservoir operation, with studies of water conditions before and after impoundment and operational problems of water level fluctuation.

As pointed out by Dr. Sunder Lal Hora, research work jointly by engineers and biologists is absolutely necessary in the design of proper fishways in dams and fish locks. The facilities of our research stations can be made use of for this purpose.

In his paper, Dr. Hora sounds a timely note of caution to all those who are entrusted with the planning of multi-purpose schemes. There is a close relationship between the living and the non-living elements of our natural resources. They should be considered together in the conservation and the utilization of these resources. The use of one resource or class of resources without due consideration for the welfare of the others is likely to result in a loss from a national stand-point.

MR. R. KAHAWITA (in correspondence): I have read the Symposium with interest and commend as a suitable and timely subject to be taken up in connection with Multi-purpose Reservoir Projects not only in India but in any part of the world. I am more so convinced of the need of such co-ordinated action between the water conservation engineers and the biologists, after what I saw somewhere in 1945 at Mettur Dam in Madras Presidency. That year, due to shortage of water, millions of fish were just allowed to die below the dam and in the tail race without any consideration of conserving the fish population in the stream between Mettur Dam and out-fall. If some of the suggestions made by Dr. Hora had been in operation at that time, it would have been a simple matter of co-ordinated action between the two sections of operatives in a stream to conserve that fish life; but as one was allowed to act independently of the other, the result had been a whole-sale destruction of valuable national wealth which was a direct result of the type of un-co-ordinated work discussed by Dr. Hora.

I would have liked to have read a greater amplification of the measures suggested by him on conserving fish life in our water resources; but I suppose, as he has already mentioned, that such amplification is to be left to a larger organization which no doubt would be created for working out the details.

POWER DEVELOPMENT

*By K. P. P. MENON, D.Sc., Utilization Member, Central Electricity Commission,
New Delhi.*

(Communicated by Dr. W. D. West, F.N.I.)

SUMMARY

Although the Tennessee Valley Authority Project is the first one on which the unified development of the resources of a river valley has taken place on a planned basis, there has been examples of multi-purpose development in India also.

In a multi-purpose river valley development, power is almost invariably an important item. It often happens that the power output is subject to wide changes during the various seasons and for the best utilization of the power resources, it will often be necessary to supplement the hydro-electric power stations with thermal power plants.

In the allocation of costs in a multi-purpose development scheme against the various purposes, there is often a tendency to increase unduly the cost towards power development. In the interests of development of both power and industries, it is important to distribute the costs in a reasonable proportion against all benefits accruing from a multi-purpose scheme.

Among the major multi-purpose development schemes under execution in India are, the Damodar Valley Project, the Hirakud Dam Project, the Bhakra-Nangal Project, the Tungabhadra Project, the Tapi Project, the Koyna Project and the Chambal Project. A brief account of the relevant aspects of these schemes is included.

I. INTRODUCTION

The TVA experiment based on the principle of unified development of the natural resources of a region has stimulated considerable enthusiasm for multi-purpose projects all over the world. Although the idea of unified development of a river valley took definite shape only recently, following the TVA project, the principles of multi-purpose development were more or less understood in India and were actually put into practice. The Cauvery river in South India, for instance, has in its 400-mile course from Coorg to the sea, two major dams, two large power stations, several anicuts and bed regulators and a network of irrigation canals. The Krishnarajasagara reservoir on the Cauvery in Mysore helps in regulating water supplies to the Sivasamudram Power Station below and also feeds irrigation canals. Besides the Brindavan Gardens at the foot of the dam attracts a good tourist traffic. The Mettur Dam reservoir on the same river, in Madras, acts as a flood moderator and has storage for the generation of power and for the irrigation of the additional acreage in Tanjore District not previously commanded by the river. The huge reservoirs at Krishnarajasagara and Mettur are also used for fish culture. Also, there are power plants and irrigation works on the tributaries of the Cauvery.

Again on the Western Ganga irrigation canal, taking off from Hardwar and flowing down to Aligarh, power plants have been installed at a number of low head canal falls. There are seven plants with a total installed capacity of 18,900 kw. in operation and the eighth station with a capacity of 10,500 kw will be commissioned soon.

It is not claimed that the above schemes were conceived and developed as multi-purpose projects, in the same way as the TVA. Originally, irrigation was perhaps the only objective of these schemes; later on, in the course of further development, suitable steps were taken to achieve the benefits of power, flood control, etc. It is, of course, a matter of speculation, in what way these schemes would have been developed, had the principle of unified development been adopted from the very start.

2. POWER GENERATION IN MULTI-PURPOSE SCHEMES

In most multi-purpose river valley projects, power can be generated, but sometimes the requirements for power generation are somewhat in conflict with those for other purposes such as irrigation, flood control, etc. From the point of view of power, it is important to ensure that a uniform power output (as high as possible) is maintained throughout the year. On the other hand, the requirements of irrigation demand that the highest discharge be maintained during the cultivation season and that as far as possible water is conserved during the non-irrigation season. Again the requirements from the point of view of flood control are that, just prior to heavy monsoon rains, the reservoir be depleted to such a level as to enable substantial storage of flood waters with the advent of the monsoons. These conflicting considerations often result in a compromise under which the output of power would (apart from being less than what it would be, if the site is considered purely for power generation), also vary from season to season. To make up for seasonal variations in the power output of hydro systems, thermal power stations of adequate capacity are built and operated in parallel with the hydro-stations.

While talking about thermal power stations, it is necessary to disabuse an erroneous idea prevalent even among informed quarters. There is a general belief that power from hydro-electric sources will be invariably 'cheap' and that thermal power could not compete favourably with hydro-power. This is not always correct. The fact that a thermal power station requires fuel for running it, whereas there is no such expense in a hydro-station, does not necessarily lead to higher costs under thermal generation. Generally the capital costs of a hydro-station of a given capacity is considerably larger than a thermal station of a similar capacity with the result that the over-all working costs of a hydro-station is, often, comparable with that of thermal power and sometimes even higher. In other words, there can be no general rule regarding the comparative costs of thermal and hydro-power and each case has to be examined with reference to the installed capacity, operating conditions and load factor, etc.

Again coal is as much a national asset as water power; there is no reason why its economic exploitation should be discouraged. India is said to possess very large reserves of low grade fuel and these could be economically burnt in power stations sited, preferably, near the coalfields. It has to be conceded, therefore, that even in a multi-purpose river valley project, the thermal power station has a place. Although the future plans for power development in India will have larger emphasis on hydro-electric schemes, the thermal power stations will also continue, probably as a complementary adjunct to hydro-power.

3. ALLOCATION OF COSTS IN A MULTI-PURPOSE PROJECT

A multi-purpose project is planned and executed as an integrated whole; but it is necessary to know what proportion of the total cost is chargeable to the various purposes under the scheme. There is a general acceptance of the healthy principle that the charges on the scheme for the different purposes should be in proportion to the benefits derived under the respective aspects of the scheme. However, difficulty arises in translating this principle into actual practice. While the returns or revenues from the sale of power are readily assessed, the monetary evaluation of other benefits such as irrigation, navigation, flood control, soil conservation and fish culture, etc., is not so easy. As a result, there is often a tendency to increase unduly the allocation of costs under power, in order to show financial justification for the over-all project. This tendency should be resisted; not only will power development be hampered by such irrational methods of allocation of costs, but it will also injuriously affect the industrial development in the country. Full considerations should be given to the indirect benefits accruing to the community from

flood control, soil conservation, malaria control, etc., and an attempt made to make a reasonable allocation of costs against these benefits.

4. PUBLIC UTILITY POWER PLANT INSTALLATIONS IN INDIA

The statement below indicates the aggregate installed capacity of all public utility undertakings in India as at the end of 1949, classified into steam, single-purpose hydro and multi-purpose hydro-stations together with projected additions up to 1954 and 1959. It will be found that the thermal capacity is predominant now and will continue to be so in the next five-year period also. Later on, as the several hydro projects get under way, there will be a gradual reduction in the thermal installations.

Installed capacity in kw. of public utility stations

Particulars.	Steam Stations.	Hydro-Power Stations.	
		Single-purpose.	Multi-purpose.
Capacity (end of 1949)	852,639	440,979	118,100
Projected additions between 1949 and 1954	741,750	371,900	382,300
Projected additions between 1954 and 1959	210,000	294,400	522,400
Total capacity (end of 1959)	1,804,389	1,107,279	1,022,800

Figures in column 4 (above) indicate that even among the existing hydro-stations there are several, which may be called multi-purpose schemes. Among the projected hydro schemes, the proportion of multi-purpose projects will be seen to be even greater than at present.

The projected additions, shown in the above statement are worked out on the basis of information available at present. However, the actual progress on the projects depends to a large extent on the availability of finances, the necessary foreign exchange and other facilities.

5. DAMODAR VALLEY PROJECT

Amongst the several multi-purpose projects under execution in India, the scheme for the development of the Damodar river valley is very well known. The ultimate picture of power development under this project will comprise 9 hydro-stations (216 mw.) and one steam power station at Bokaro (150 mw. perhaps 200 mw. later on). These stations will be inter-connected with one another and serve the South Bihar Coalfields area, as well as Jamshedpur, Kharagpur and perhaps even Calcutta. If the proposed scheme for the electrification of the E.I.Rly. between Howrah and Moghalsarai fructifies, power will be supplied to the Railways from the Damodar Valley System.

The design of the power system of the Damodar Valley is an example of properly co-ordinated utilization of the natural resources. While the hydro capacity will be utilized to the full, as and when water power is available, the large deposits of low grade coal available, in South Bihar, will be utilized in a modern efficient high pressure thermal power station to supplement the power output in the region.

It is estimated that on the basis of multi-purpose operation of the reservoirs, the firm output of hydro-power will be only 65,000 kw. continuous. Besides, seasonal

output to the extent of 65,000 kw. will be available. The utilization of this seasonal power is rendered possible by the combined hydro-thermal operation, proposed under the project. During the monsoon months, the hydro-stations will take the base load and the steam station the peak loads. In the dry season, when the discharges in the rivers will be low, the steam station will take the base load.

The construction work on all the power plants under the project will not be taken up simultaneously, but the programme of works will be co-ordinated with the demand for power in the Damodar Valley as well as the availability, if any, of surplus power in neighbouring power systems such as the Hirakud project.

In the first stage of the power plant programme, now under execution, the Tilaiya hydro-station and the Bokaro thermal station will be completed by 1953. Konar I, Maithon and Panchet Hill power stations will probably follow the first installations. It is not possible at this stage to anticipate the programme of work in regard to the other stations.

Among the loads which are expected to be connected up to the Damodar Valley Power System in the initial stages are :—

1. Coalfields	50 mw.
2. Aluminium Factories—(existing and expansions)	30 mw.
3. Jamshedpur Iron & Steel Works and neighbouring area	30 mw.
4. Locomotive Factory at Mihijam	5 mw.
5. Telephone Cables Factory at Mihijam	1 mw.
6. Export of Power to Calcutta and Kharagpur	25 mw.
	<hr/>
	141 mw.

6. MULTI-PURPOSE DEVELOPMENT ON THE MAHANADI RIVER

The ultimate development on the Mahanadi river will comprise three major dams located at Hirakud, Tikarpada and Naraj. In the first stage the construction works on the Hirakud Dam only is being undertaken. The power plant installations under the Hirakud Scheme will comprise two stations, one at the foot of the dam and the other at the terminus of a power channel about 17 miles long. In final stage, the power station at the dam will have 6-37.5 mw. generating sets operating at heads varying between 79 feet and 112 feet and that at the end of the power channel, 4-24 mw. generating sets operating at a head of 90 feet. Initially, however, the power plant installations will be limited to 2-37.5 mw. sets at the dam station and 2-24 mw. sets at the canal power station.

The ultimate aggregate power output from the Hirakud project is estimated to be 218 mw. at an average load factor of 70 per cent. It is proposed that the canal power station will operate as a base load station at 100 per cent. load factor, whereas the dam power station will take the peaks, the load factor of its operation being about 56 per cent. Besides, the reservoir at Hirakud will be capable of supplying an additional secondary power to the extent of about 40 mw. which can be converted to firm power by suitable inter-connections with other systems, if and when necessary.

An extensive transmission network will enable supply of power from Hirakud over a large part of Orissa; possibly, also in the adjacent states of Madhya Pradesh and Bihar. It is also likely that the Hirakud System will be inter-connected with the Damodar Valley grid in the north as well as the Machkund power station in the south.

The area served by the Hirakud power station has a large potentiality for industrial development. Among the loads visualized to be connected to Hirakud are an

iron and steel mill (30,000 kw.), Aluminium production (65,000 kw.), larges scale lift irrigation (24,000 kw.) and power supply to a large number of towns and villages in Orissa. Supply from Hirakud is expected to be available in 1953-54.

7. BHAKRA AND NANGAL PROJECTS

A third multi-purpose development scheme now under execution in India is the Bhakra-Nangal Project. As far as power development is concerned, this project can be divided into two distinct stages, viz. (i) the Nangal Power Scheme and the (ii) Bhakra Dam Scheme. Work is proceeding actively at present on the Nangal Scheme, which comprise the construction of 2 hydro-electric power stations on the Nangal canal, each with a capacity of 48,000 kw. and a network of transmission lines for supply of power to Delhi, Panipat, Ambala and a large number of towns and villages in the Punjab, Himachal Pradesh and PEPSU. The Nangal transmission grid will also be inter-connected with the transmission system of the existing Jogindernagar power station at Ludhiana.

Agreement has been reached between the Punjab Government and the Delhi Central Electric Power Authority for the supply of 20 mw. of power from the Nangal Power Station to Delhi. The Punjab Government are also understood to be considering plans for the establishment of industries, both large and small, so that the power supply from the Nangal Scheme may be utilized fully.

According to plans, the two Nangal Stations will each have ultimately an additional 24,000 kw. generating set and probably the Bhakra scheme will have six 80,000 kw. generating sets. However, it is too early to say, when the installation of these power plants will be undertaken. The programme of power plant installations should be closely related to the load demand. Therefore, additional generating plants at Nangal and the power plants at Bhakra may probably not be taken up until the initial power capacity of Nangal is utilized to a reasonable extent.

8. TUNGABHADRA SCHEME

Another multi-purpose development scheme is on the Tungabhadra river. The Tungabhadra project, being executed jointly by the Madras and Hyderabad States, has for its main objectives irrigation and generation of power. So far as Madras side is concerned, plans have been prepared for the construction of a power station at the dam site (22.5 mw.) and a second power station at Bukkasagaram at the end of a power channel (15.0 mw.). These two power stations will feed a network of 66kv. lines in the Ceded Districts. Pending the commissioning of these stations, the Madras Government have arranged to build up the transmission and distribution network in the Ceded Districts and are building up load with the help of power purchased from the Jog power system of Mysore. Thus, when the Tungabhadra power stations are completed, and commissioned, they will have a fair amount of ready-built load and this would help the financial working of the scheme considerably.

9. TAPTI SCHEME

In the Bombay State, the Central Waterpower, Irrigation and Navigation Commission are undertaking the construction of the Kakrapar project on the Tapi river. Although originally the scheme was designed mainly from the point of view of irrigation, it was found that by a suitable modification of the dam and other works, a large measure of flood control, perennial irrigation, generation of substantial blocks of power, and even perennial navigation facilities could be provided. Proposals have therefore been finalized for increasing the height of the dam suitably, which will enable the installation of a power plant at the dam site. Also, a second power plant will be installed at the end of a power channel at Kamapur. The ultimate aggregate installed capacity of power plant in this project will be 216,000 kw.

made up probably of 9-24 mw. units. It has been proposed that in the initial stages, the power plant installations should be limited to 5-24 mw. sets which will give a firm output of about 96 mw. The power station will be inter-connected with Ahmedabad City Power Station in the north and the Bombay power system in the south and will also feed the local area around Surat.

The chief advantages of this project are as follows:—

- (1) The amount of civil works required in connection with the power development under this project is comparatively small.
- (2) The irrigation portion of the project is self-supporting with the result that the incidence on the cost of power generation will not be too heavy.
- (3) As the location of the Kakarpara project is midway between the main load centres of the Bombay State, viz. Ahmedabad and Greater Bombay areas, this project is in a position to serve both these areas economically.
- (4) Under present acute conditions of power supply in the Bombay State, the Kakarpara power project can be completed comparatively quickly, thus affording the much needed relief to the Bombay power system.

Although the main works on the project are proceeding, final decisions in regard to the implementation of the power development in this project have not yet been taken. It is, however, hoped that this would be expedited and the necessary works proceeded with early.

10. KOYNA RIVER DEVELOPMENT PROJECT

Another major multi-purpose development scheme in the Bombay state on which preliminary work is in progress, is the Koyna River Development. The scheme which will cost over Rs. 40 crores, involves the construction of a dam about 350 feet high across the Koyna river impounding about 154 m.c.ft. of water of which about 44 m.c.ft. will be used for irrigation and 69 m.c.ft. for power generation. The power output of the first phase of development of the scheme will be 320,000 kw. The main drawback of this scheme is the huge capital cost and the magnitude of the work involved; it might take the good part of about 10 years to complete the scheme.

11. CHAMBAL RIVER DEVELOPMENT

The development of the Chambal river is being considered jointly by the authorities of Rajasthan and Madhya Bharat. There will be three large reservoirs at Kotah, Rawatbhata and Chaurasigarh and at each of these locations, power plants aggregating to 42,000 kw., 62,000 kw. and 72,000 kw. respectively will be installed. In the initial stages, however, work will be proceeded on with the construction of power plant at Chaurasigarh only and transmission lines to supply power supply at the major centres in the area, viz. Jaipur, Jodhpur, Gwalior, Indore, etc., will be built. The Central Electricity Commission have recently carried out a comprehensive load survey of the Madhya Bharat and Rajasthan areas with a view to design a suitable grid system in connection with the Chambal hydro-electric scheme. Based on this survey a suitable network of power lines will be built and supply extended to the various load centres in the area.

12. CONCLUSION

The statement given in the appendix gives a broad idea of the various river valley schemes being pursued as multi-purpose projects. The tendency for utilizing the natural resources of a river valley in a unified and co-ordinated manner, is gradually gaining ground in India. The Government of India are considering at present a suitable legislation to regulate and develop the inter-State rivers and river valleys and when this proposed legislation is placed on the Statute Book, it will further assist the unified development of India's rivers and river valleys.

APPENDIX

Multi-purpose hydro-electric scheme (either under execution or likely to be taken up in the near future)

Name of Project	Ultimate installed capacity of power plants*	Other benefits
<i>West Bengal.</i>		
1. Mor Reservoir Project ..	4,000 kw.	Irrigation.—600,000 acres. Also flood control and prevention of soil erosion.
<i>Bihar.</i>		
2. D.V.C. Projects—		
(a) Tilaiya ..	2-2,000 kw.	Irrigation—9 lakh acres, also flood control, coal conservation, industrial and domestic water supply, transport facilities, electrification of railways, industrial development, national defence, recreation, fish cultivation, soil conservation, etc.
(b) Konar I ..	2-10,000 kw.	
(c) Konar II and III ..	2-11,000 kw.	
(d) Maithon ..	2-20,000 kw.	
(e) Panchet Hill ..	2-20,000 kw.	
(f) Aiyar ..	2-22,500 kw.	
(g) Balpahari ..	20,000 kw.	
(h) Bermo ..	25,000 kw.	
<i>Bombay.</i>		
3. Radhanagari Hydel-cum-Irrigation Project.	4-12,000 kw.	Irrigation—19,000 acres.
4. Tapti Valley Development, Kakrapar Project.	9-24,000 kw.	Irrigation—6,35,000 acres, also flood control and navigation.
5. Koyna Hydro-Electric Scheme.	320,000 kw.	Irrigation—440,00 acres.
<i>Madras.</i>		
6. Tungabhadra Hydel-cum-Irrigation Scheme.	5-7,500 kw.	Irrigation—110,000 acres.
<i>Orissa.</i>		
7. Mahanadi Valley Development—Hirakud Project.	6-37,500 kw. and 4-24,000 kw.	Irrigation—1,094,953 acres, also flood control, navigation, soil conservation, silt control, fish culture and recreation.
<i>Punjab.</i>		
8. Bhakra-Nangal Project ..	Nangal: 6-24,000 kw. Bhakra: 6-80,000 kw.	Irrigation—3,581,497 acres
<i>Uttar Pradesh.</i>		
9. Mohammedpur Hydel Project.	3-3,500 kw.	On Ganga Canal which is intended for irrigation.
<i>Bhopal.</i>		
10. Kolar Nadi Hydel-cum-Irrigation scheme.	3-5,000 kw. and 2-750 kw.	Irrigation—41,000 acres.
<i>Madhya Bharat and Rajasthan.</i>		
11. Chambal Hydel-cum-Irrigation Project.	Chaurasigarh: 72,000 kw. Rawatbhata (Mowar): 62,000 kw. Kota: 42,000 kw.	Irrigation—700,000 acres and navigation and fish culture.
<i>Rajasthan.</i>		
12. Jawai Rivor Project (Jodhpur).	2-1,200 kw. 2-750 kw.	Irrigation—70,000 acres.

* Figures indicate the ultimate capacity proposed; but during implementation of the schemes, the installations will be suitably staged.

DISCUSSION

DR. K. L. RAO—It is stated in the paper that the thermal power may be cheaper than the hydro-electric power, specially if the cost of the dams is to be borne on the Power Development.

This statement is rather difficult to understand and may mislead some people to think that 'Hydro-power' is not essential. The entire industrial prosperity of Southern portions of Madras state is due to the development of hydro-electric power in Pykara, Mettur and Papanasam where the entire cost of the dams is charged to power. Even in T.V.A. it is admitted that the prosperity of the valley is solely due to hydro-electric power and even if the entire cost of the scheme is borne by power, the scheme would still have proved highly economical. A large number of dams were constructed across rivers Ken and Kee, under Galloway scheme, in United Kingdom, to develop the hydro-electric power and support the thermal power supplied to the city of Glasgow.

MINERAL UTILISATION

By W. D. WEST, M.A., Sc.D. (Cantab.), F.N.I., F.R.A.S.B., Director, Geological Survey of India, Calcutta.

SUMMARY

The main functions of a multi-purpose river project are irrigation, flood control, power production and navigation. The two latter have a direct influence on mineral utilisation.

If power production can be increased it will aid mineral and metal production by cheapening it. With more abundant power, mining can be mechanised, smelters and refineries to reduce the ores to metals can be introduced, and rolling mills can be built. Further, the production of cheap electric power will enable the better quality coal to be used for purposes other than power production.

Navigation by river or canal, because it is relatively cheap, will also assist mineral production, for one of the main difficulties hampering the mineral industry in India is the high cost of transport.

But perhaps the main advantage of a multi-purpose scheme to mineral production is the opportunity it provides for co-ordinated planning of mineral utilisation. No country is self-sufficient in minerals, or in the products derived from them. But the more it can be made self-sufficient, in a sound economic way, the better. What applies to a country also applies to an area, for the essence of successful industrialisation is close co-ordination of as large a number of related industries as possible.

The setting up of such an authority as the D.V.C. should encourage co-ordinated industrial development. By making an inventory of the total mineral resources of an area, and by planning the best utilisation of these resources, private enterprise, aided and encouraged by State assistance, may be co-ordinated so as to produce the most fruitful results; and such co-ordinated industrialisation will lead to the utilisation of minerals in local industries, as against their export in the raw state. The Damodar Valley, with its richness in minerals, provides an ideal case for planned mineral utilisation.

Certain drawbacks, such as the flooding of mineral deposits by reservoirs, or by seepage from reservoirs, have to be guarded against. The possibility of rendering some seams in the Bokaro coalfield unworkable by the construction of the Bokaro reservoir, for example, needs careful investigation.

The subject of mineral utilisation, which Mr. Khedker and I are to speak about today, is not one which can be discussed in very precise terms. There are certain directions in which a multi-purpose river project can obviously benefit mineral utilisation, and these will be referred to in a general way.

Of the main functions of such projects: irrigation, flood control, power production and navigation, it is the two last which will have a direct influence on mineral utilisation.

It is obvious that if power production can be increased and cheapened it will aid in mineral and metal production. That these projects will increase power production is clear. Whether they will also be able to provide it at a cheap rate is another matter, and will depend upon what proportion of the cost of a scheme can be borne by the other functions of the scheme such as irrigation. Ordinarily the production of power alone by the construction of a costly dam in relatively level country cannot compete in price with its production from coal where supplies of this mineral are abundant and cheap. But the advantage of a multi-purpose scheme is that the cost of construction can be covered by the revenue derived from more than one source, and it may thus be possible to produce electric power relatively cheaply.

Assuming, therefore, that it is possible to provide cheap power, then a great deal can be done with it to develop the mineral wealth of the area. Mining can be mechanised, smelters and refineries to reduce the ores to metals can be introduced, and rolling mills set up. The film that was shown yesterday illustrated well the way in which the minerals of the Tennessee valley were being utilised in the industrial development of the valley.

In this connection there is one further point that should be mentioned which has particular reference to India, where there is an abundance of second grade coal but not so much good quality coal. By producing cheap electric power, which can be used not only for industrial purposes but also for the electrification of railways, the better quality coal can be used for purposes other than power production and transport.

Navigation by river or canal, because it is relatively cheap, will also assist mineral production, for one of the main difficulties hampering the mineral industry in India is the high cost of transport. For example, the cost of transporting gypsum from Rajasthan to the Sindri fertiliser plant in Bihar is more than four times the cost of the gypsum at the mine.

These advantages which I have mentioned are obvious. Less obvious, though perhaps almost as important, is the opportunity such schemes provide for the co-ordinated planning of mineral utilisation. No country is self-sufficient in minerals, or in the products derived from them. But the more it can be made self-sufficient, in a sound economic way, the better. What applies to a country also applies to an area, for the essence of successful industrialisation is the close co-ordination of as large a number of related industries as possible. The Ruhr valley is an example, and the Damodar valley, and perhaps also the Mahanadi valley, may one day be equally flourishing. Therefore, the setting up of such an authority as the Damodar Valley Corporation is important, because it should be in a position to encourage, if not to direct, co-ordinated mineral development.

If we consider the mineral potentialities of these two valleys, we find that the Damodar valley is unusually rich in those minerals required for industrial development. Over 40 per cent of the mineral production of India (judged by value) comes from Bihar. But the Damodar valley also includes the Raniganj coalfield of West Bengal, so that altogether this valley is already responsible for more than half the total mineral production of India.

The Mahanadi valley has the essential minerals, except high grade coal, required for the iron and steel industry, the aluminium industry and the cement industry. As this valley includes parts of Orissa that have not yet been surveyed in detail, its mineral resources may prove to be greater than is at present thought.

The benefits to be derived from these two multi-purpose river schemes, therefore, are likely to have a considerable influence on the utilisation of the mineral wealth of India, particularly if that utilisation is properly planned and co-ordinated with existing private enterprise. Moreover, such co-ordinated industrialisation will lead to the utilisation of minerals in local industries, as against their export in the raw state. I may refer particularly to two minerals: mica and bauxite (aluminium-ore).

India produces more than 70 per cent of the world's best mica, but it is practically all exported. It is true that it is securing valuable foreign exchange to the extent of about Rs.8 crores a year, a large proportion of which is in dollars. But would it not be better if at least a portion of it could be utilised in an indigenous electrical industry, at present almost non-existent.

The aluminium produced in India (less than one-third of the country's requirements) cannot at present compete in price with the imported metal. For successful cheap production it is necessary to work in large units and to have an abundance of cheap electric power. These two requirements may be realised in a fully developed Damodar or Mahanadi valley.

Finally, reference may be made to certain disadvantages that may arise if the plans are implemented without a full appraisal of their effects, such as the losses that may be incurred through the reservoirs flooding valuable mineral deposits. Two examples may be mentioned which call for careful examination.

The Aiyar dam, which will hold up the upper waters of the Damodar river, will flood, according to J. B. Auden and P. K. Ghosh, about one-quarter of the Ramgarh

coalfield. Though the coal in this field is poor in quality, it has a local use, and about 600,000 tons a year are being mined. There is also a possibility of this coal being used for the production of synthetic petroleum, though for the time this proposal has been dropped.

A more serious case is the proposed Bokaro reservoir, to be located between the East and West Bokaro coalfields, which will flood about seven square miles of coal measures in the West Bokaro field. It is clearly very necessary to carry out more detailed investigations before the construction of this dam is decided upon.

In such cases it is necessary to balance the disadvantage of losing a certain amount of coal (or of having to mine it under difficult conditions) against the advantages to be derived from constructing the reservoir.

MINERAL UTILISATION

By V. R. KHEDKER, M.Sc., Geologist, Geological Survey of India, Calcutta

(Communicated by Dr. W. D. West, F.N.I.)

SUMMARY

The cheap hydro-electric power from a river valley project connotes industrial development. Minerals constitute a major raw material factor in modern industry. It is a fortuitous and happy circumstance that India is endowed by Mother Nature with a fair proportion of minerals—a bounty which is not bequeathed uniformly over the world. The mineralised zones in India are: Bihar, Orissa, Madhya Pradesh, Vindhya Pradesh, Mysore, Madras, Rajputana and Assam. The river valley projects now well under way are the Damodar, Hirakud and Bhakra.

The area which benefits by a river project extends to such distances around it over which electric power can be transmitted and mineral resources exploited. Thus, the Damodar Valley Project will benefit Bihar, West Bengal and North Orissa. Incidentally this area is the richest mineralised zone in India and holds vast reserves of most of the minerals which serve as vital raw material for industry.

The imports into India, of capital and consumer's goods, in the manufacture of which minerals are required, amount to Rs.700,000,000 annually. This figure emphasises the possibilities which exist for the development of domestic manufacturing industries.

Compared with Great Britain and U.S.A., the development so far achieved by India in the field of industry is very poor indeed.

Modern industrial practice has become very complicated and has transgressed the limits of private enterprise. It now requires from the State, safeguards, guarantees, protection and sometimes even capital. All these factors lead to nationalisation which is not hailed by all as a success in Britain today. The nearest solution seems to be the State sponsored, semi-independent and autonomous river valley project, if promotion of industry in an active sense were to be included as one of its multi-purpose activities. In India, it is already well known that, with a few exceptions, private enterprise has not succeeded in building up as stable a mineral industry as is desirable, and the proper and scientific exploitation and conservation of minerals, which are an irreplaceable national asset, has rarely been kept in view.

The reserves of mineral raw material in the Damodar Valley and adjacent region (including apatite, bauxite, chromite, clay, coal, copper-ore, gold, iron-ore, mica, refractory minerals, sulphur, vanadium ores and rare minerals, etc.) constitute a tremendous potential for metallurgical—ferrous and non-ferrous, chemical, heavy chemical, cement, ceramic, refractory, insulation, glass and paints industries. Similar possibilities exist in the other mineralised areas of India mentioned above. All this potential national wealth awaits exploitation in an integrated pattern as soon as cheap electric power from river valley projects becomes available.

Thus, it is evident that utilisation of minerals in industry has to be made an important, economically defined and direct function of multi-purpose river valley projects which should be designed to cover as much of the mineralised zones of India as is possible.

The series of scientific and technical operations which constitutes a 'Multi-purpose River Valley Project' form an accepted process today for the economic advancement of

The 'open sesame' of industry an area. Certain pre-requisites are, however, necessary, viz. a river with reasonable water, sites for dams, irrigable terrain down-stream and existent or possible installations for consuming the power to be generated. Electricity is the 'open sesame' of industry.

The generation of cheap hydro-electric power connotes industrial development.

Minerals and their constituents, either refined as such, or chemically or metallurgically processed form the basic and often major raw material factor in any mechanised industry. Unfortunately, minerals are not abundant everywhere. They are a bounty from Mother Nature, which she has distributed with caprice and scrutiny! It

Minerals—Nature's bounty is the privilege of the Geologist, the custodian of this bequest, to state, that Mother Nature has endowed India with a fair proportion of this bounty. The mineralised zones in India, so far known, are located in: South Bihar, Orissa, Central and eastern

Madhya Pradesh, Vindhya Pradesh, Mysore, South Madras, Rajputana and Assam. In addition, there are smaller and isolated areas, e.g. Cutch, Godavari basin, etc.

The area which benefits by a river valley project extends to such distances around it, over which it is economically possible to transmit electric power or exploit mineral resources. Taking the Damodar Valley Project as an example, it will be seen that this project will help to develop central and southern Bihar, West Bengal and northern Orissa. Incidentally this area forms the richest mineralised zone in India and holds vast reserves of the minerals which serve as vital raw material for industry.

The imports into India, of capital and consumer's goods, in the manufacture of which, minerals or their constituents are utilised, amount to about Rs.700,000,000 annually. This figure is based on such statistics of imports as are available which are, however, rather incomplete. Even so, this figure clearly emphasises the possibilities which exist in the development of domestic manufacturing industries.

Taking 1870 as approximately the year from which a wider mechanisation of industry commenced, the progress made by India when compared with that achieved by Britain and America indicates great disparity. Wars have always imparted a tremendous stimulus to industry. Even with the two major wars during the first half of this century, the only outstanding industrial units which developed in India are the iron and steel, textile, cement and a few units manufacturing mechanical and electrical machinery. It is patent that the capacities of all these units are far below the domestic requirements. Thus, if tropical inertia is not to be attributed as the prime cause of this disparity and slow growth, then other causes will have to be found. It is true that mobilisation of large capital is not easily possible in India, as also the emphasis on quick returns on the part of the investors. Perhaps, these were some of the important causes.

However, modern industrial practice has become very complicated and has transgressed the limits of private enterprise. In almost all the advanced countries, industry now seeks from the State, safeguards, guarantees, protection and sometimes even capital. All these factors lead to nationalisation, which has, however, aroused a deal of controversy and criticism in Britain today, where the organisation of capital has reached a high degree of specialisation. Conditions regarding the industrial set up in India are perhaps quite different. All the same, the experience available abroad should be helpful in rationalising, the mechanics of the investment of capital in India, particularly in terms of the river project, which offers the nearest solution in being State sponsored, semi-independent and autonomous. A set up which is obviously only too congenial for promotion of industry to be included as one of its multi-purpose activities. Further, in India, it is already well known that with a few exceptions, private enterprise has not succeeded in building up as stable a mineral industry as is desirable in terms of the existing potential. What is more, the proper and scientific exploitation and conservation of minerals, which are an irreplaceable national asset, has rarely been kept in view. There are many areas in India with a fairly large mineral potential and also rivers, awaiting the formation of river projects. In some instances, the project may comprise of but a single dam.

In the Damodar Valley and adjacent region there are large reserves of minerals, mineral assemblages and rocks which serve or will serve as raw material for industry. Some of these minerals are: apatite, bauxite, chromite, clay, coal, copper-ore, gold, iron-ore, mica, refractory minerals, sulphur, vanadium-ore and rare minerals, etc. These reserves constitute a tremendous potential for such basic industries as: metallurgical—ferrous and non-ferrous, chemical, heavy chemical, cement

Operational area of a river valley project

Prospects of industrial development

Slow progress so far

State participation in industry

Possibilities in the Damodar Valley Project

ceramics, refractory, insulation, glass and paints. The products of these various industries are used either directly or are processed through the subsidiary and fabricating electrical and mechanical engineering industries which finally yield the capital and consumer's goods. (Khedker, 1949.)

The other river projects now well under way are the Hirakud and the Bhakra. The possibilities of industrial development due to them are more or less on the same

Conclusion lines as those mentioned above. Similar prospects of industrial development exist in the other mineralised areas elsewhere in India. All this potential national wealth awaits exploitation in an integrated pattern as soon as cheap electric power from river valley projects becomes available.

Thus, it is evident that utilisation of minerals in industry and development of industry have to be made as direct functions of the river valley projects which should be planned and designed to cover as many of the mineralised zones of India, as is possible.

REFERENCE

- Khedker, V. R. (1949). Mineral Resources of the Damodar Valley and Adjacent Region and their utilisation for Industrial Development. (In Press). Published by the Damodar Valley Corporation, Anderson House, Alipur, Calcutta.

CEMENT AND MULTI-PURPOSE PROJECTS¹

By J. B. AUDEN, *M.A., Sc.D. (Cantab.), F.N.I., Superintending Geologist,
Geological Survey of India, Calcutta.*

SUMMARY

After an enumeration of the different classes of Portland Cement, a discussion follows on specifications, with particular regard to magnesia and alkalis. Experimental work has shown that expansion takes place with cements containing 5 per cent magnesia, due to the hydration of periclase to brucite, and it is considered unlikely that any relaxation of the specified limit of magnesia should be allowed. The alkali reaction is discussed on the basis of work recently done in America, and potentially reactive minerals in the basic lavas of the Deccan Traps are considered. The use of pozzolan substitutes for a part of the cement is discussed in the light of work done by the Bureau of Reclamation, and materials which may be of value as pozzolans in India are briefly outlined. Finally the question of beneficiation of impure limestones is discussed in regard to certain limestones in northern India.

CONTENTS

	<i>Page</i>
1. Types of Portland Cement	545
2. Specifications	546
3. Economy in the quantity of cement used in concrete	548
4. Beneficiation of Limestones	550

The object of this article is to stress certain aspects of the cement problem as they concern multi-purpose projects in India. Some of the data are derived from published books and articles, but it is thought desirable to assemble the information and discuss its application to Indian conditions.

1. TYPES OF PORTLAND CEMENT

The bulk of the Portland Cement manufactured in India corresponds to normal cement of Type I according to the present classification. In 1930 an important advance was made in the U.S.A. in connection with the construction of the Boulder Dam, a massive structure 726 feet in height from lowest foundation, 660 feet in base thickness, and 3.24 million c.yds. in volume. With normal Portland Cement, and without special cooling, the mass concrete of the Boulder Dam would have taken over a century to cool down to temperature equilibrium, according to the calculated gradient on the upstream face of the dam of 40°F. at the base and 72°F. at the top. Consequently, a special low heat cement was developed, and artificial cooling was adopted, in order to accelerate the attainment of equilibrium. The low-heat cement had a decreased amount of C_2S and C_3A , and a larger proportion of C_2S . The great dam projects now under consideration in India have necessitated the initiation of experimental work in this country, and some years ago various types of low-heat cement were manufactured on an experimental scale at one of the A.C.C. factories in northern India. The A.C.C. have just recently announced the capacity for full-scale production of this type of cement. Other types of cement, suitable for special purposes, are also extensively manufactured abroad.

¹ Published with the permission of the Director, Geological Survey of India.

The characteristics of the 5 main types of Portland Cement are tabulated below (Bogue, 1947, p. 25). In addition have been given certain normal and specialised cements manufactured in the United States.

PORTLAND CEMENT

	Standard types of Portland Cement					Manufactured types				
	TYPE I. Normal.	TYPE II. Moderate Heat of Hydration.	TYPE III. High Early Strength.	TYPE IV. Low Heat.	TYPE V. Sulphate Resisting.	Permanents Standard Portland Type I.	Permanents Low- Heat for the Shasta Dam, Type IV.	Boulder Dam Low Heat.	Grand Coulee Dam. Modified Low Heat.	
SiO ₂	21.3	22.3	20.4	24.3	25.0	23.56	25.30	23.4	21.9	
Al ₂ O ₃	6.0	4.7	5.9	4.3	3.4	3.97	4.12	5.21	5.00	
Fe ₂ O ₃	2.7	4.3	3.1	4.1	2.8	3.05	3.2.4	4.62	4.29	
CaO	63.2	63.1	64.3	62.2	64.1	65.34	64.34	..	..
MgO	2.9	2.5	2.0	1.8	1.9	1.30	1.06	..	..
SO ₃	1.8	1.7	2.3	1.9	1.6	1.49	1.24	..	..
Ign. Loss	1.3	0.8	1.2	0.9	0.9	0.51	0.57	..	..
Alkalis	..	..	..	..	..	..	0.52	{ K ₂ O—0.14 Na ₂ O—0.43		
Insol. Res.	0.2	0.1	0.2	0.2	0.2	..	0.13	..	..
Uncombined CaO	..	..	..	..	..	..	0.60	..	..
C ₃ S	45	44	53	28	38	51.4	34.0	..	..
C ₂ S	27	31	19	49	43	28.8	47.0	..	..
C ₃ A	11	5	11	4	4	5.4	5.4	..	..
C ₄ AF	8	13	9	12	9	9.3	9.6	..	..
CaSO ₄	3.1	2.8	4.0	3.2	2.7	..	..	..	..
MgO Max.	5.0	5.0	5.0	5.0	4.0	..	..	..	..
SiO ₂ Min.	..	21.0	..	..	24.0	..	..	..	..
Al ₂ O ₃ Max.	..	6.0	..	..	4.0	..	..	..	..
Fe ₂ O ₃ Max.	..	6.0	..	6.5	4.0	..	..	..	..
C ₃ S Max.	..	50	..	35	..	..	..	..	..
C ₂ S Min.	..	..	..	40	..	..	..	..	..
C ₃ A Max.	..	8	15	7	5	..	..	..	..
Finess (Sq.cm./gr.)	1,600	1,700	..	1,800	1,800	..	..	..	..

For high dams located in narrow gorges, involving mass concrete with a base width of 500 feet or more, there is little doubt that true low-heat cement of type IV will have to be used in conjunction with artificial cooling. For dams of lower height and base width, even if of large total volume on account of great length, such as at Koyna and Kakarapar, type II cement, with a moderate heat of hydration, will suffice, without possibly the adoption of special measures for artificial cooling.

2. SPECIFICATIONS

From table (1), it is seen that the maximum permissible proportion of magnesia is 5 per cent in types I–IV inclusive, and 4 per cent in type V. The average content of magnesia in the typical cements tabulated above is only 2.22 per cent. From tables given by Lea and Desch the average for 10 samples of British cements is found to be 1.02 per cent, and 2.60 per cent for 12

samples of American cements. The average magnesia content in 27 analyses of American cements cited by Witt (page 181) is 2.04 per cent, agreeing closely to that for the typical cements listed in the table given above. It may be noted that in the British Standard Specification for Portland Cement, the limit of magnesia is fixed at 4.0 per cent, which is one per cent less than in the American specifications for types I-IV.

It is sometimes stated that the criterion regarding magnesia can be relaxed, but there is no certainty that this is really so. According to Bogue, the available evidence is that magnesia does not enter in combination with the other ingredients of the cement, and the danger of its presence beyond a certain percentage lies in the hydration of periclase to brucite. Assuming a specific gravity of 3.65 for periclase and 2.4 for brucite, the hydration of periclase to brucite results in an expansion in the molecular formula volume of 120 per cent. This reaction is well known in metamorphic rocks, the Pencilite of the Tyrol consisting of brucite and calcite, the former derived from periclase. Autoclave experiments have shown that a large expansion, even years after setting, takes place in cements with 5 per cent of magnesia, but that no expansion occurs if the magnesia content is 3 per cent or less (Bogue, 1947; 503, 504). The recorded expansion and cracking of concrete, such as at the Parker Dam, has been found to be due to the alkali reaction discussed below. It is possible, however, that the extensive and valuable research done on the alkali reaction in concrete may have diverted attention away from delayed reactions arising from hydration of periclase in concretes containing cement relatively rich in magnesia. Inasmuch as most cements have a magnesia content well below the specified limit, it is unlikely that the periclase-brucite reaction is of general significance, but it deserves serious observation and research in view of the very recent decision of the Indian Standards Institution to raise the magnesia limit of Portland cements in this country to six per cent.

Some of this expansion to brucite can be reduced if the cement clinker is quickly chilled, with the resulting isolation of periclase, partly in solid solution and partly as crystals, within the glass ground mass, since the periclase then has no chance to hydrate to brucite (Bogue, p. 105). But cements with a high glass content have also higher heats of hydration, which is a most undesirable property in the case of cements of types II and IV. It may be assumed therefore that the magnesia content should remain as low as possible, and should be less than 4.0 per cent in the cement, and preferably below 3.0 per cent. This implies that the magnesia content of the raw slurry before calcining should not normally exceed 2.6 per cent, and if possible should be under 2.0 per cent.¹

Another criterion which has recently assumed importance in America is the quantity of alkalis in the cement. Due to the necessity in some of western States

of the U.S.A. of employing acid volcanic aggregate which frequently contains opaline silica, deleterious reactions have set up between the alkalis in the cement and the unstable hydrated silica in the aggregate. This results in the formation of silica gels, expansion of the concrete and extensive cracking, the most noteworthy example being the Parker Dam on the Colorado River. Research has shown that this particular reaction can with few exceptions be prevented, even though chemically unstable aggregate is used, provided the alkali content of the cement (soda, together with potash estimated as soda) remains below 0.60 per cent. Besides opaline silica, other deleterious minerals are:—chalcedony in chalcedonic cherts; chalcedony with or without opal in siliceous limestones; volcanic glass, devitrified glass and tridymite in acid and medium volcanic rocks; and hydromica and finely divided quartz in some phyllites. For full details reference should be made to the important paper recently published by Blanks (1949), which is based on the work of the petrographers McConnell and Mielenz.

¹ Reference may be made to the footnote on page 550.

So far as is known, no research has been done on this problem in India, doubtless because concretes in important structures have not been subjected to swelling and cracking. There is, however, occasion for much research work to be done on the basalts of the Deccan Traps, which contain chalcedony, celadonite and zeolites. The zeolites consist of hydrated aluminium silicates variously combined the soda, potash, lime and magnesia. The bonds holding these atoms are weak and base-exchange reactions are characteristic of minerals of the zeolite group, which is the basis of their use as water softeners. In March, 1949, the Geological Survey was asked to give an opinion as to whether or not certain zeolitic basalts found near the Kalyan power-house could be used as aggregate for concrete. No data were available, but it was considered that the zeolites might set up base-exchange reactions with the cement in the concrete:—

- (a) between any free lime in the cement and alkalis in the zeolites;
- (b) between alkalis in the cement and zeolites contain exchangeable lime.

Subsequently, the paper by Blanks came to hand in which it is seen that work on zeolites has already been done in the United States. Failure is reported to have occurred in a concrete employing zeolite-bearing anorthosite as aggregate. This aggregate had 1.4 per cent by weight of replaceable bases. In view of the fact that the Deccan Traps occupy 200,000 square miles of area in Western India, and basalts must of necessity be the main source of aggregate, the reactivity of zeolites should not be overlooked.

It is uncertain to what extent the limit of 0.60 per cent alkalis will be demanded in manufacturing cement for mass concrete work in India. The alkali content appears to be of significance only when the aggregate used contains minerals which are chemically reactive. Moreover, the alkali reaction can in some cases be controlled by the substitution of a certain proportion of pozzolan, as was done in the case of the Davis Dam. Over many parts of north, east and south India the aggregates are probably not reactive, but this supposition may require qualification after research has been done on concretes found to be unsound. Poor quality concrete may exist in several localities, on the defects of which no particular studies have been made.

Since, however, the alkali content of cements has been found to be of great significance with certain types of aggregate, it is clear that out of any representative group of limestones sampled, at least 20 per cent of the analyses should include soda and potash. It is probable also that the alkali content of cements will be included in future specifications.

Alkalis are not usually analysed in Indian limestones, but the following two limestones may be cited as containing a low alkali content:—

- (a) Rohtas Limestone, Sone Valley Portland Cement Co., Japha:
'Alkalis, etc.' 0.42 per cent.
- (b) Langrin Limestone, Khasi Hills, Assam:
Alkalis 0.36 per cent.

On the other hand, the average alkali content of four samples of crystalline limestone from Bhainse Dobhan in Nepal is as high as 2.47 per cent. These alkalis are largely in combination with alumina and silica as feldspars.

3. ECONOMY IN QUANTITY OF CEMENT USED IN CONCRETE

The most probable change in construction methods for mass concrete work is likely to be the substitution of pozzolanic constituents for part of the cement now employed. The practice for mass concrete work on dams until recently has been to employ a barrel of cement (376 lbs.) per cubic yard of concrete, or 0.63 tons of cement

per 100 cubic feet of concrete. The latest work in the States and other countries has shown, however, that pozzolan-portland mixtures provide a strong concrete, and it is to be expected that great savings in cement will be gained in India provided suitable pozzolan substitutes can be located within economic distances of projects and cement factories. This becomes of great importance in the case of dams such as that projected across the Kosi River in Nepal, which will be of the order of 10 million cubic yards of concrete, and would necessitate according to normal practice the use of about 1.7 million tons of cement.

Pozzolans are defined by F. M. Lea (p. 460) in the Symposium on the Chemistry of Cement, published by the Royal Swedish Institute for Engineering Research, Stockholm (1938), as follows:—

‘Siliceous materials which, though not cementitious in themselves, contain constituents which at ordinary temperatures will combine with lime in the presence of water to form compounds which have a low solubility and possess cementing properties.’

Pozzolans were first developed by the Romans, who mixed pumice and obsidian with the hydraulic cements which they developed more than two thousand years ago.

Blanks (1949 (2), p. 177) has described the ideal portland-pozzolan mixture for dam-concrete as follows:—

					Quantities per cubic yard of concrete.	
					Volume c.ft.	Weight in pounds.
Cement, Type II	..	..	..	0.96	189	} 279
Pozzolan	..	..	..	0.56	90	
Water	..	..	..	2.07	130	
Entrained air	..	..	..	0.81	..	
Aggregate	..	..	..	22.60	3,670	
				27	4,079	

Ratio cement/pozzolan 2 : 1 by weight.

The particular pozzolan employed in the example cited above has a specific gravity of 2.58, but other pozzolans are likely to exceed this in unit volume weight. In the United States one of the pozzolan materials in common use is pumicite. This material was employed in the proportion of 20 per cent by weight in the Friant Dam and 35 per cent by weight in the Altus Dam. The pumicite incorporated in the Friant Dam was obtained from volcanic beds in the close vicinity and had a fineness of 2990 cm.²/gr., 98.8 per cent passing 200 mesh sieve and 97.8 per cent passing 325 mesh (opening 0.04 mm.). Inasmuch as this particular material consists largely of acid glass, it would be expected that unfavourable reactions might have been set up with alkalis in the cement. In fact, however, the fineness modulus, or specific surface area, is so large that such reactions as occurred must have been greatly accelerated, and were presumably consummated before the concrete had set. Pumice is also used in the preparation of light-weight concretes which require a high value for thermal insulation, but in this example there is no saving in cement, since 6.7 sacks (554–658 lbs.) are used per cubic yard.

In the Davis Dam, Colorado River, the pozzolanic constituent was calcined shale obtained locally, used in a 20 per cent replacement of cement by weight. The primary reason for the pozzolanic addition in this case was that the local volcanic aggregate is chemically reactive, and the pozzolan was required to prevent the expansion which would otherwise have occurred from the alkali-aggregate reaction. T. E. Stanton provides the following data (quoted by R. F. Blanks, 1948, Table 5).

Effect of Pozzolanix admixture on several reactive cement-aggregate combinations.

Cement Nos.	Alkalies per cent	Percentage expansion in 40 weeks at 70° F.	
		No admixture	Calcined Monterey shale
1	0.47	0.067	0.014
2	0.47	0.168	0.015
3	0.51	0.118	0.016
4	0.62	0.255	0.011
5	1.17	0.230	0.086

With regard to possible pozzolan materials in India, it is unfortunate that pumice is not found in this country, although it may occur in the volcanic regions of Koh-i-Sultan and Koh-i-Tuftan in Baluchistan. In south India it has long been the practice to add *surki*, or crushed brick, to the cement, and it is probable that this may act as a pozzolan rather than merely as an inert constituent. Materials which deserve further study in India as possible sources of pozzolan may be tentatively tabulated below:—

- (a) calcined crushed shale, coaly Gondwana shale, phyllite;
- (b) crushed blast-furnace slag;
- (c) crushed cherty limestone and cherty dolomite;
- (d) crushed rhyolite and trachyte in the Deccan Traps;
- (e) crushed ash beds in the Deccan Traps;
- (f) calcined fullers earth of Jodhpur and Jammu;
- (g) calcined marls containing considerable argillaceous content in addition to calcareous phases, such as around Lucknow;
- (h) crushed laterite.

It is not suggested that all the materials indicated in the above list will be found suitable as pozzolans, but research work on them would be desirable.

If suitable pozzolans can be developed in India it is clear that there will be a great reduction in the quantity of cement required for mass concrete work. The saving in cement in the example given by Blanks is 50 per cent, but the reduced costs incurred thereby must be offset to some extent by the cost of obtaining and transporting pozzolan substitutes, as well as of calcining and grinding them.

4. BENEFICIATION

Since many of the limestone deposits which have a chemical composition suitable for the manufacture of cement are already taken up, or will shortly be utilised, the future development of the cement industry will necessitate locating factories near limestone properties which lack the required chemical specifications until they have undergone some form of beneficiation.¹ This will apply not only to factories

¹ Subsequent to the delivery of this address, the author learnt that the Indian Standards Institution had very recently decided to raise the upper limit of magnesia in Indian Portland Cements to six per cent, a fact which has been incorporated in the printer's proof at the end of paragraph 1, page 547. The reason for this decision appears to be to permit the use of certain Vindhyan limestones which would otherwise have been debarred on account of relatively high magnesia. It is not known if beneficiation experiments have been carried out on the

erected to satisfy what may be termed the normal domestic consumption of cement, but in particular to factories which may have to be put up for the construction of the major dams involving the use of 1 to 2 million tons of cement for mass concrete. Some of these major dams are located in isolated areas in the Himalaya, which are far removed from existing plants. The transport of such large quantities of cement is costly and, as far as practicable, it will be necessary to erect factories close to the dam sites. Many of the carbonate rocks of the Himalaya, in which all the high structures will be located, are dolomitic. Other deposits, although low in magnesia, tend to have excess silica and alumina and cannot be employed directly in the manufacture of cement without beneficiation. In such cases, the economics of long haulage from existing factories in the plains will have to be studied in relation to those ensuing from factories erected closer to the sites, and utilising limestones requiring beneficiation.

The beneficiation of limestones for cement manufacture developed shortly before the last war, three prominent plants being at Catasauqua (Pennsylvania), Parana (Argentina), and Hennenman (South Africa). Beneficiation was also used extensively for upgrading magnesite deposits in the United States which were being developed for the manufacture of metallic magnesium. The main process involves the use of flotation, an adaptation of ore-dressing methods to non-metallic processes. Another process is based on differences in specific gravity, but this has had little direct application to the cement problem, except in conjunction with flotation. A third system involves the use of chemical methods for the separation of magnesium from calcium in dolomite. The flotation method is described in two articles in *Pit and Quarry* for 1938 and 1940, kindly supplied by Messrs. F. L. Smidth & Co. (Bombay) Ltd., concerning plants in South America and South Africa, and in greater detail in a paper by Englehart (1940) for the plant at Catasauqua, Pennsylvania. Space forbids a description, but the following summary regarding flotation agents used may be quoted from Read (1943, p. 229):—

‘Collecting agents for calcite include both fatty and resin acids and their soaps and emulsions. For siliceous materials, from which a high-silica material is retained and a material lower in silica but containing excessive amounts of alumina and magnesia is rejected, the collecting agent is a long-chain aliphatic amine. Frothing agents are monohydric alcohols, resins and cresylic acid. Calcium lignin sulfonate, sodium silicate, and soda ash also have a part in the process.’

Unfortunately, satisfactory geological descriptions of the limestone deposits of the three plants described in the articles cited are not available. The Valley Forge limestone is probably metamorphic and moderately coarsely crystalline, as otherwise it would not have been possible to give the mineral mode of the rock. Dolomite formed 10 per cent of the material, presumably as discrete isolated crystals, capable of separation by flotation methods. The South African material must also be moderately coarse, since the calcite has been deposited in a sandy soil.

Beneficiation of carbonate rocks by flotation methods has evidently been concerned mainly with treatment of the following lithological types:—

- (a) Crystalline metamorphic limestones in which the minerals occur as microscopically distinct phases. Magnesia exists in the form of crystals

limestones in question, but flotation improvement may be a possible alternative to the procedure actually adopted. The propriety of relaxation of the standard specification regarding magnesia has been, it seems, accepted by some cement experts, notwithstanding the known influence of high magnesia in engendering expansion. The text of this paper must stand as it was given, and it will be of great interest to study the subsequent behaviour of concrete, particularly mass concrete, employing high-magnesia cement, thereby establishing whether or not the laboratory experiments have general practical validity.

of dolomite, pyroxene, amphibole or mica, which are capable of separation from calcite. Silica is present in the form of quartz, or combined as feldspar, mica and ferro-magnesian silicates.

- (b) Crystalline magnesite, in which it is required to concentrate the magnesite from a gangue of undesirable calcite, dolomite or quartz phases.
- (c) Non-magnesian limestones with excessive silica, alumina or ferric oxide, occurring as elastic constituents microscopically distinguishable from calcite.

There is, however, a group of dolomitic limestones and dolomites located within the Himalaya, both as part of the Krol overthrust unit, and within the window zone of Larji, Shali, and Garhwal, which are microcrystalline or cryptocrystalline, and consist of a very intimate mixture of dolomite and calcite, with dolomite in excess, sometimes to the complete exclusion of calcite. In view of the belief expressed in some quarters that magnesium carbonate and calcium carbonate can be separated from each other in dolomite by ore-dressing methods, it is necessary to stress that dolomite is a distinct double salt mineral. X-ray studies have shown that the calcium and magnesium atoms in dolomite lie alternately along trigonal axes in association with groups of CO_3 -atom combinations lying on the central axis. Consequently, it is quite impossible to separate lime and magnesia in dolomite by flotation, and only chemical methods can be employed for this purpose. Under favourable conditions of crystallinity it is possible to separate the distinct mineral phases magnesite, dolomite and calcite, but the breakdown of dolomite into its constituent radicles by flotation cannot be achieved.

Many of the Himalayan dolomitic rocks are, however, so fine-grained that it is improbable that normal flotation methods could be used to separate calcite from dolomite. This might be achieved on a laboratory scale by centrifuging and possibly flotation, with very incomplete separation, but as a commercial proposition such processes cannot presumably be considered. There is scope for research on this problem in the case of the less fine grained rocks containing calcite in excess of dolomite, such as certain of the dolomites of the Krol-C substage.

The matter was referred to Messrs. F. L. Smidth & Co. (Bombay) Ltd., and the following is a quotation from their reply:—

‘The cost of the flotation process depends to a very large extent on the crystalline structure of the limestone available and for your information we would like to add that we have already carried out some tests on Indian limestones.

We have found that, for instance, limestone from the Tinnevely area can be easily purified by the flotation process whereas we have also found that limestone of the type found in the Bhopal State cannot be purified to such an extent that it will be suitable for the manufacture of cement.

With the flotation process the content of magnesium carbonate will generally not be reduced but if magnesium is present as magnesium silicate this mineral can generally be removed from the purified raw material.’

This same company indicate that in flotation plants already established the extra cost involved is approximately Rs.4 per ton of cement, a figure which includes depreciation and interest on the capital expenditure of the plant, but they stress that costs vary from case to case according to the method of treatment adopted. It may be expected that this figure will be considerably exceeded on account of present-day inflationary prices, and the necessity of recruiting highly paid skilled personnel to run the specialised flotation plants.

Among limestones in northern India which deserve consideration from the point of view of beneficiation may be mentioned the following:—

- (a) The Mandhali limestones of Kalsi, Dehra Dun District, which consist of alternations of limestones of the composition of natural-cement rock with more siliceous limestones. The limestones are fine-grained, with

- uniformly low magnesia, but contain variable quantities of minute elastic quartz grains and argillaceous impurities.
- (b) The crystalline metamorphic limestone of Bhainse Dobhan, Nepal, already mentioned above, which have somewhat excessive silica and alkalis in the form of quartz and feldspar. The magnesia, which tends to occur beyond the specified limits, occurs partly as ferro-magnesian silicates and partly as dolomite. These limestones probably resemble those at Valley Forge, Catasaqua.
 - (c) The crystalline metamorphic limestones of Chhanngu in south-east Sikkim, similar to those at Bhainse Dobhan.
 - (d) Some of the more siliceous and magnesian limestones of the Rohtas stage in Mirzapur District, which are interbedded with natural-cement limestones.
 - (e) Crystalline metamorphic limestones of Gangpur.

REFERENCES

- Blanks, R. F. (1948). The Use of Portland-Pozzolan Cement by the Bureau of Reclamation. Address delivered at the Spring Meeting of the Portland Cement Association, May 11, 1948, in New York City.
- (1949). Modern Concepts applied to Concrete Aggregate. *Am. Soc. Civ. Eng. Proc.*, 75, p. 441.
- (1949). Better Concrete for our future Dams. *Eng. News Record*, 1-9-49, p. 175.
- Bogue, R. H. (1947). The Chemistry of Portland Cement. New York.
- Englehart, G. K. (1940). Flotation as applied to modern Cement Manufacture. *Indust. & Eng. Chem.*, 32, p. 645.
- Loa, F. M. and Desch, C. H. (1940). The Chemistry of Cement and Concrete. London.
- Read, W. T. (1943). Industrial Chemistry, New York.
- Witt, J. C. (1947). Portland Cement Technology, New York.

DISCUSSION

DR. K. L. RAO—It seems to be necessary to draw the pointed attention of the cement manufacturers in this country to the urgency of producing 'Rapid Hardening' type and 'Medium Heat' type of cements. The rapid hardening cement is necessary in all structural work and is practically the only type used in construction of buildings and bridges, etc., in the United Kingdom. It enables removal of early formwork. In the construction of dams, whether built of stone or concrete, it will be greatly advantageous to use 'Moderate heat' cement instead of the present ordinary cements. The manufacture of the two types of cement mentioned above do not involve any elaborate deviation from the present methods and I am sure the manufacturers in India will readily agree to the production of these cements provided the necessity is pointed out to them.

It may be noted that *surki* or burnt brick powder was used as an admixture to cement by replacing 20% of the cement in the construction of Mottur Dam. *Surki* satisfies all the criteria for a good puzzolana, for cement-*surki*-sand mortar develops greater durability and impermeability, without loss of compressive strength, than cement-sand mortar only.

MALARIA AND ITS CONTROL

By B. C. DAS GUPTA, *Director of Health Services, West Bengal, Calcutta.*

(Communicated by Dr. A. C. Ukil, F.N.I.)

SUMMARY

A short historical review of the various stages of development of knowledge from the ancient to the modern times regarding the clinical recognition, treatment, causal factors, drug administration and methods of control of malaria is given. Its main epidemics, geographical distribution, epidemic and endemic nature, seasonal and other periodic prevalence and mortality and morbidity have been mentioned.

Three cardinal factors, viz., Parasite, Transmission and Host Resistance, and several secondary factors in the causation of the disease have been described. In connection with the primary factors the types of malaria parasite and their cycles of development in man and mosquito, reservoir of infection, types of the anopheline mosquito which transmit the disease with a short description of their bionomics, the reaction the man gives to infection and the associated problem of latency and relapse have been touched upon. The secondary factors described are:—
(a) Topography and climatological factors, viz. rainfall, humidity, temperature, subsoil water and winds; (b) Human element, viz., age, sex, race, literacy, economic and nutritional stage; (c) Human activities in the spread of malaria, viz:—

- (i) migration, aggregation and dispersal;
- (ii) agriculture;
- (iii) man-made malaria;

(d) natural catastrophies, viz., famine, flood, drought, storms and cyclones.

Prevention and Control

The importance of a malaria survey as an essential preliminary to the planning and organisation of control measures has been emphasised. The practical control measures have been discussed under four main heads: viz:—

- (a) Measures directed against the parasite and reservoirs of infection.
- (b) Measures directed against the vector species.
- (c) Measures directed against man-made malaria.
- (d) Control of man and community.

The measures discussed under (a) are: (1) clinical prophylaxis by various anti-malarial drugs, and (2) casual drug prophylaxis.

A three-pronged attack has been described under (b) viz. (1) anti-larval, (2) anti-adult and (3) protection from bites of mosquitoes. Among the anti-larval measures the uses and utilities of oil, paris-green and DDT and the value of the indirect method of various drainage installations, filling and certain naturalistic methods, such as, altering the flora of the breeding places, polluting, shading, introduction of natural enemies, etc., have been discussed. In this connection the various hydro-technical measures in the management of water such as flooding and flushing, agitating, river-training, impounding, sweetening and freshening, salinifying, intermittent drying, fluctuating and sluicing operations have also been mentioned.

The anti-adult measures discussed are: (a) naturalistic, e.g. zooprophyllaxis, etc.; (b) mechanical, such as, jungle clearing, site-selecting, mosquito-proofing, use of bell nets and chemical repellants; (c) killing of adult mosquitoes by means of pyrethrum extract and DDT spraying and their advantages in the modern anti-malaria operations.

In regard to (c) the importance of anticipation and preplanning after a survey has been emphasised and certain lines of control suggested in specific cases.

The measures mentioned under (d) are: (1) segregation of active cases and gametocyte carriers; (2) combating malnutrition; (3) educational measures; (4) legal measures; (5) raising of economic level, and (6) social considerations.

HISTORICAL EVOLUTION OF THE KNOWLEDGE OF MALARIA AND ITS CONTROL

Malaria is contemporaneous with the history of man and even today is a single disease which directly and indirectly contributes the largest share of mortality in

many countries of the world. Yet it is one of the most important preventible diseases in the world. Through centuries man has been learning how to combat it, slowly revealing its secrets and devising methods of control.

It is one of the oldest recorded diseases recognised by the Hindu, Chinese and Chaldean texts written many many years before Christ.

Gallen who practised in Rome (180–200 A.D.) described the clinical symptoms. Thus Greeks and Romans were the first to be convinced that there was a causative relationship of the intermittent fever with swampy terrain. Here was the beginning of malaria epidemiology which led to the adoption of drainage in ancient Greece and Rome as a measure against the disease. Unfortunately, for the next 1,500 years there was no advancement made regarding the cause or therapy of this fever. In the 17th century began the search for a remedy and the export of Quina Quina bark as a substitute for the Peruvian bark as an adulterant marked the next milestone of progress in regard to malaria control. Lancisi and Rasoi in mid-18th century conceived of a parasitic origin of malaria—the former even postulating that the intermittent fevers of his time were transmitted by insects. To Laveran in Algeria and Ross in India we owe the establishment of the hypothesis first propounded by Sir Patric Manson in 1894.

In the first quarter of the 20th century interest in malaria mainly centred round malaria control measures. Remarkable advances have been made since, such as improved technique for studying experimental malaria, a deeper understanding of the biology of the malarial parasites by Stephens in 1932 and Knowles in 1938, Also the work of Fairley and his colleagues in 1947 and later by Shortt and others, has thrown new lights on the tissue phases of this parasite—the anophelone groups of mosquitoes identified, charted and the bionomics of the Vector species in different parts of the world studied. The recent proof of the power of DDT in spray killing adult mosquitoes offers the first financially feasible method of controlling malaria in much of the rural tropics where cost of anti-larval methods on such a vast scale is prohibitive.

I would now like to place before you certain facts and features of this disease without which it is not possible to stress the control measures suggested later in this paper.

Malaria has appeared in the form of pandemics and epidemics in various parts of the world since the 16th century. Of the major epidemics in recent times, mention may be made of the Russian epidemics of 1923–25, the great Ceylon epidemic of 1935, the great Brazil epidemic of 1938 and the Egyptian epidemic of 1943. In India a devastating epidemic, affecting the Punjab, the western parts of U.P. and Sind appeared in 1938 and again in 1942, while the eastern provinces of India, namely, Assam, Bengal, Bihar, Orissa, parts of U.P. and C.P. were visited by a severe epidemic in 1943 and 1944.

Geographical distribution of malaria can be divided broadly under two heads: the Endemic and Epidemic areas. The endemic areas generally involve regions between 45° north and 40° south slightly varying in different continents. Within this belt fall parts of Europe, Middle East, India, Ceylon, Far East, parts of Africa, North America, South America, Central America and parts of Australia. In India, the distribution of malaria varies: regions above 5,000 ft. (except Quetta), Eastern Bengal, north-eastern portion of Brahmaputra Valley in Assam and the narrow strip of valley in the Madras Presidency are relatively free. In the rest of the country malaria is indigenous. The epidemic zones cover a large number of countries including Russia, Brazil, Egypt, North Asia, Iraq, Iran, the Punjab, Sind and western districts of U.P., Ceylon and Southern China.

Another feature of the disease is that it prevails periodically in the form of either long-term or short-term epidemic waves. The long-term periodicity was noticed as far back as 5th century B.C. by Celli who states that 6 big waves ran over Europe, some waves running over several centuries at a time. The short-term

waves may show almost a regular amplitude of 5, 6, 7 or 8 yearly periods depending generally upon the environmental set-up, and communal immunity. In Bengal, the 6-yearly characteristic is noted as against 8-yearly periods in the Punjab. In the endemic regions there is generally a short annual heightening of incidence depending upon warmth, humidity, rainfall and other associated factors which facilitate propagation of the vector. In India and other parts of the tropics the main malaria season is in Autumn with a subsidiary period in spring. This, however, is reversed in the foothill regions in southern and western India where the Spring instead of the Autumn is the main malaria season.

MORBIDITY AND MORTALITY

As a cause of sickness malaria is the most important disease in all the tropical and sub-tropical countries. The Malaria Commission of the League of Nations estimated that nearly 650 million persons suffer from it every year in the world, of which in India alone according to a conservative estimate 100 millions suffer in ordinary years. The disease is common to all ages and sexes, but in endemic areas children, because of lack of resistance, both general and specific, suffer more. In ordinary years mortality does not exceed 1%, but during epidemics mortality may be 10 to 12 times the ordinary figures. In India nearly 1 million persons die every year and the rate of 8 per thousand would not be an unreasonable estimate (Sinton).

FACTORS CAUSING MALARIA

An appreciation of factors causing malaria is necessary in order to devise ways and means of control:—

I. *Primary factors*

(a) Parasites.

(b) Reservoir of infection.—Man is the only reservoir of infection so far as the transmission of human malaria is concerned. Infected persons showing gametocytes (sexual forms) in the blood are the only source from which infection spreads. In endemic areas children and non-immune adults produce gametocytes in large numbers and they, therefore, form the most potent source of infection.

(c) The Vector.—Human malaria is naturally transmitted through the bites of certain species of female anophelene mosquitoes because it is the females who require blood feed for reproduction or oviposition and because it is only in them that the sexual cycle of the development of the parasite takes place. Not all anophelens can carry malaria though there are about 200 species of them in the world. In India not more than 7 species have so far been incriminated as the main vectors of malaria. These are.

- | | | |
|-------------------------------|----|---|
| (i) <i>A. Culicifacies</i> | .. | Mainly responsible for malaria throughout India except Bengal, Assam, Baluchistan and foothill regions. |
| (ii) <i>A. Minimus</i> | .. | Terrai and Doonars. |
| (iii) <i>A. Fluviatilis</i> | .. | Foothill regions of Nilgiris and Western Ghats. |
| (iv) <i>A. Philliponensis</i> | .. | Deltaic Bengal. |
| (v) <i>A. Sundaicus</i> | .. | Coastal regions of Bengal, Orissa, northern parts of Madras up to Vizag. |
| (vi) <i>A. Stephensai</i> | .. | Cities like Bombay, Bangalore, Lucknow and Cutch. |
| (vii) <i>Q. Superpictus</i> | .. | Baluchistan, N.W.F. Province. |

A knowledge of the bionomics of anophelene mosquitoes is a necessary preliminary to adopting control measures. It is of considerable importance both in connection with epidemiological studies and in relation to control. Knowledge regarding the place and time of oviposition, factors controlling larval development and mating, feeding, flight and resting behaviour of adults together with other factors governing the reaction of the insect to the environmental changes should be acquired.

The incidence of malaria in a locality depends upon 3 factors:—

- (1) Gametocytes carrier.
- (2) Density of vector species.
- (3) Food habits of the mosquitoes.

In order to control malaria, the number of anophelens in a locality must be brought down below the critical density. The factors which determine this density are:—

- (i) temperature;
- (ii) humidity;
- (iii) nature, extent and nearness of breeding places to human habitation;
- (iv) available food supply to larvae and pupae;
- (v) presence or absence of natural enemies;
- (vi) proximity of shelter for adults on emergence;
- (vii) season of the year; and,
- (viii) extent of man-made interference.

Malaria whether treated or not tends to be self-limited. The primary attack may be followed by a complete recovery or by a series of latent periods alternating with relapses. The intervals become progressively long and relapses less acute until cure occurs or death ensues. Immunity in malaria is mainly acquired through long contact with infection.

II. *Secondary Factors*

(1) These are environmental, climatological factors such as rainfall, temperature and humidity, subsoil water. One often sees a close relation between ground water levels and endemic malaria with high spleen rates corresponding to areas of high subsoil water level; for instance the irrigation projects in the Punjab and Sind resulted in a high water level and increased malaria. This point should, therefore, be borne in mind while undertaking irrigation projects; but if the vector species is not a surface water breeder, a high water level has no effect whatever on malaria. Strangely enough, in deltaic Bengal, inverse correlation between high subsoil water and the incidence of malaria has been noticed.

(2) *Human activities in the spread of malaria*—Migration, aggregation and dispersal.

The migration of soldiers, labourers, pilgrims and others from malarious areas spread malaria. There is an old expression 'tropical aggregation of labour' describing conditions leading to local epidemic of malaria commonly seen in large engineering projects, large labour concentrations as in Malaya and logging operations as in Burma. It is due to the intermingling of the susceptible population with the local infected population who are comparatively immune.

(3) *Agricultural*—Throughout the world and especially in the tropics malaria and agricultural practices are intimately related. Where the farmers practice archaic methods with poorly planned irrigation, it is usual to find malaria greatly intensified due to the breeding of vector species in the collection of water provided by farmers themselves.

(4) *Man-made Malaria*—Activities leading to creation and increased facilities for breeding of malaria-carrying mosquitoes are:—

- (i) Badly planned, constructed and maintained drainage;
 - (ii) Obstruction to natural drainage by construction of roads, railways and canal embankments;
 - (iii) Creation of breeding places, such as borrow-pits quarries, brick fields, tanks, fountains, etc.
 - (iv) Bringing in an increased influx of water into an area without proper drainage. Introduction of large irrigation projects such as Sukkur Barrage, Mettur Dam.
 - (v) Domestic breeding—places.
- (5) Natural catastrophies such as famine, floods, drought, storms, and cyclones.

SURVEY PRECEDES ADOPTION OF CONTROL MEASURES

Before understanding and undertaking malaria control on a large scale one has to make a thorough survey of the area to be dealt with.

A malaria survey is an examination of the status of malaria in a community or area. It has got varied utilities:—

- (i) in planning practical control;
- (ii) to measure and record the progress and results of prevention programme;
- (iii) to demonstrate losses due to malaria and gain from prevention;
- (iv) to assess the potentiality of malaria in an area where big engineering schemes, e.g. railways, dam, irrigation projects, etc. are contemplated or where an aggregation of labour population is expected.

The survey may take the shape of a quick reconnaissance as in war condition or more or less complete survey for the long range planning of control measures or it may be a continued scientific study based on new exact measurements over a period long enough to reveal cyclic characteristics and other epidemiological features of the disease. This survey is usually made (i) by collecting available records of past malarial conditions, reports of doctors, travel diaries, official and non-official records, weather reports, reports of constructional projects and history of migration and pilgrimage; (ii) study of topography, contour, communication and approach, preparation of a map with possible details of natural and artificial breeding places; (iii) study of socio-economic conditions; (iv) malariometric studies by house-to-house visits, recording population, age, sex, occupation, etc., morbidity and mortality statistics, aggregate malaria index, parasite, haemoglobin and splenic indices, study of anophelin factor—types, density, distribution of larvae and adults, oocyst indices and the bionomics of vector species, source and nature of breeding places, their flora and fauna. Finally, analysis of the data collected is made and findings recorded.

Having attended to this as an essential preliminary to scientific planning of malaria control, one proceeds to plan and organise control measures themselves.

Control Measures

The control measures may be divided into four main heads:—

- (i) Measures directed against the parasites and reservoirs of infection;
- (ii) Measures directed against the vector species.
- (iii) Measures directed against man-made malaria.
- (iv) Control of man and community.

MEASURES DIRECTED AGAINST PARASITES AND RESERVOIRS OF INFECTION

A—The attack on the parasite is best carried out by treating the malaria patients with drugs and using them for prophylactic purpose among people who have been

exposed or are likely to be exposed to infection. Treatment in the acute stage of the disease destroys the parasites and may thus prevent formation of gametocytes which play an essential rôle in the transmission of the disease.

Practical experience together with modern experimentation has made it clear that no drug as yet marketed will, in safe doses, prevent sporozoites from taking root and developing in men. Malaria cannot yet be eradicated from a community by distribution of drugs and chemoprophylaxis even though it may be of value under military conditions, is but of limited value in civil life where only partial prophylaxis or suppression of disease with some reduction in morbidity and mortality may be achieved.

B—What has proved of greater value and wider application than drugs for treatment is the measure directed against the vector species. A three-pronged attack is generally carried out:—

- (i) anti-larval;
- (ii) anti-adult;
- (iii) protection from bites—the last as a measure of personal protection.

(i) *Anti-larval Measures*—The cost is high and it takes about six weeks to produce results. They can be adopted in localities where brooding places are not too extensive. Recourse has been made to agents which act as larvicides: oil was the main agent used to kill aquatic stage of mosquitoes. Ross was the first to suggest its use and demonstrated it first at Serra Leone in 1899. Till about 20 years ago oiling was the main method employed in India for malaria control. But oil is a costly substance. Its transport especially to areas where malaria is the biggest problem is costly and difficult. Its inflammability renders its storage difficult and it is liable to be misused and abused. Subsequently came Paris Green into the field and relief was felt that malaria control had become less difficult and less expensive. But procurement and storage of a suitable diluent as also its more frequent application than oil presented difficulties. In the case of both, weather conditions acted as a limiting factor besides objections to their application in growing food crops were raised on the grounds of damage to crops. Above all came the supreme difficulty of locating and treating the numerous breeding places at shorter intervals than was necessary with oil. The cost was also high and it limited its operations to urban and military requirements leaving the vast rural areas where malaria was the greatest scourge untouched on these counts.

These difficulties have been sought to be overcome by what are known as 'permanent measures', which included (i) drainage, open and sub-soil, fillings, etc., to obviate the need for repeated chemical treatment. Drainage, however, is not a panacea in mosquito control. It has its value when a suitable type is applied in proper situations. However, when suitable it can be accomplished by the use of surface drains and ditches, vortical drains, pumps, tide gates, subsoil drains and other devices depending primarily upon vector species and their bionomics, and local factors such as topography contours, soil, wooded areas, climate, rainfall as well as on material available and on agricultural and economic conditions.

Filling is another method largely employed. Natural filling often occurs as a result of guiding or river training.

Naturalistic methods are cheaper and more rational. Williamson tried them in Malay Peninsula followed by Senior White in Joypore Hill, Russel and Jacob in Ennore near Madras, Hackett and Vonkat Rao. These consist of (a) altering the flora of breeding places, e.g. Iyengar considers a complete and tight covering water hyacinth does not allow of breeding anophelines; (b) in case of some vectors, exposing the water surface to sunlight or shade; (c) polluting water with herbage packing or with sewage and sullage. Other naturalistic methods consist of mechanical management of water by hydro technical means, such as flooding, silting, flushing, sluicing, agitating, sweetening and freshening, salinifying, intermittent drying,

fluctuating level of impounded water as proved by Hackett in U.S.A., as also in Tennessee Valley. In certain countries 'species sanitation', a more economical method has been practised and found more useful than general anti-anophelene measures. It was tried by Watson in Malaya (in 1921), Senior White (1938) in India, Iyengar in Bengal (1944). It was found to be more economical also.

The various methods mentioned above are anti-larval measures which are difficult to carry out, in many instances expensive, requiring a good deal of work in the fields under trying conditions. Thus began the era of adult control.

Adult Control—Evident enthusiasm was seen amongst malaria workers when malaria control was envisaged through the use of pyrethrum which was also considered cheaper and more effective than other methods employed hitherto. In anti-adult spraying with pyrethrum the spacing of the intervals should be based on rational methods depending on the tropisms of the particular vector species concerned. Here again is illustrated the cardinal principle of malaria control, namely that there is no single royal road to success. The road to Malaria Control varies with the vector and its bionomics. Some vectors spend all but a small part of each gonotrophic cycle inside the house as against others who spend but the shortest period and are thus not available inside the house for spray killing. The pyrethrum age yielded to DDT during World War II, when effective malaria control made all the difference between victory and defeat. Anti-larval measures were found useless for protection of troops in camps on the line of communications. Pyrethrum was found ineffective and an effective insecticide which would lend itself to be used at sufficiently long intervals so as not to cause more than minimum interference to other war activities was needed. DDT having fulfilled both these conditions proved to be an ideal and popular insecticide.

There is no doubt that DDT is a great advance over other insecticides and constitutes a landmark in the history of disease control. Its utility in long-range anti-malaria policies is, however, still under study and cannot yet be taken as proved. Viswanathan and Rao tried it in large-scale operations in Bombay and observed similar reductions in the number of the vectors. Similar results have been reported from Kenya, Italy, Greece, Ethiopia and Venezuela. The value of DDT spray killing of adult mosquitoes is mainly due to its residual killing effect when sprayed over surfaces upon which mosquitoes and flies alight for resting. The residual effect may last as long as three months depending upon the strength of the solution sprayed. It has no knock-down effect like that of pyrethrum but has a killing effect all the same, the maximum lethal effect being obtained with higher strength of the solution—100 mg. (DDT) per sq. ft. being more effective than 60 mg. doses.

Viswanathan and Rao have shown by extensive and wide application of DDT in every house in several districts that there has been remarkable reduction in the incidence of malaria. Collateral with reduction of malaria they have observed considerable reduction in infant mortality, death rate from bowel diseases and incidence of plague. What is even more spectacular is the saving of hundreds of thousands of men from the ravages of the disease thus improving cultivation and raising of crops and the economic gain obtained therefrom. DDT therefore has revolutionised malaria control and to the Tropical Malariologist who was so far struggling with small-scale malaria projects—chiefly anti-larval—it has come as a boon in the form of an implement of 'premises sanitation'.

DDT spray has to be repeated after 6–8 weeks intervals depending on the vector prevailing in the locality. Three sprays during the transmission season covering a total period of 5–6 months have been found sufficiently effective. With the first spray there is a remarkable reduction in the number of mosquitoes but usually they begin to re-appear in similar density by about 6 to 8 weeks. Hence the need of repeated spray. In this connection field experiments are in progress to compare the relative efficacy in malaria control of a single dose—180 mgs. per sq. ft., two applications of 90 mgs. per sq. ft. or three applications of 60 mgs. each. The results

will place us in a better position for determining the optimum dosage and frequency of DDT application in malaria control. This will also have a bearing on the cost of labour—one of the principal items of expenditure. In spite of the obvious financial advantage of a single DDT spray, it has been the experience of Viswanathan and Rao that multiple smaller doses of DDT are to be preferred for many reasons—one of them being that they are less likely to stimulate the emergence of resistant strains of anophelines, the possibility of which has been already agitating the minds of malariologists.

In addition to indoor DDT spraying which has now been accepted as the most effective single measure of malaria control there are other measures on which much reliance cannot be placed even as individual attempts at malaria control far less as a community measure.

Control of Man-made Malaria

Knowingly or unknowingly man, by his own action, has interfered with nature in many of the projects apparently executed in his own interest and thus created malariogenic conditions. A few instances may be cited as imperfectly constructed culverts, drainage systems, irrigation without counter-drainages, borrow-pits, casual siting of villages and labour lines, all kinds of dam, canal, hydroelectric bridge, road and railway constructions, carried out without the slightest regard for mosquito prophylaxis, indiscriminate spacing of jungles, construction of embankments on the river obstructing natural drainage, flooding and flushing, causing malaria.

It is not uncommon to find employers taking large labour forces into malarious areas for construction projects but making no provision for combating malaria in spite of the knowledge that many such projects had to be abandoned owing to devastation by malaria. Malaria hazards have not infrequently been created by the impounding of water in reservoirs for power, flood controls or irrigation. Such projects in endemic areas require proper plans and continuous supervision if man-made malaria is to be avoided. The Tennessee Valley Authorities in the southern States of U.S.A. have provided good examples of how malariogenic conditions may be minimised by long-range planning and operational water management.

Control Measures

The best way to control malaria in these situations is to anticipate such happening before any project is undertaken. All probabilities should receive consideration and a planned scheme should form a part of the operation and a suitable and proper organisation should be provided to carry out the measures. If there is one field where the engineers and the medical officers could work in intimate co-operation it is this field of control of man-made malaria. Control measures to be adopted are determined according to the particular situation and attendant circumstances. Certain broad principles to be followed in this connection are:—

- (1) For tropical aggregation of labour—proper siting of lines away from highly infected villages and proper organisation for curative and preventive work should be provided.
- (2) Prevention of creation of borrow-pits, brickfields and quarry pits.
- (3) Clearance of jungles—may have an adverse effect in regard to malaria.
- (4) Embankments across the line of drainage can be allowed if provision is made for natural drainage. Sufficient number of culverts and bridges must be provided. Damodar River Embankment is the cause of malaria in certain parts of West Bengal.
- (5) In the construction of rail roads and highways the borrow-pits created should be provided with proper drainage.

- (6) In the construction of dams and Barrages care should be taken to avoid the occurrence of leaks, seepages and overflow or if they occur, ensure their collection and drainage. Provision should be made for fluctuating the water-level at will. There should be arrangement for flushing or sluicing the channels. Even after the construction work is over, a permanent anti-malaria organisation should be maintained.
- (7) In the irrigation system particularly in the intermittent kind, accumulation of water in low-lying areas and depressions should be prevented. A counter-drainage should be provided in all irrigation systems. If water-logging ensues, subsoil drainage with proper out-fall will lower water sufficiently to prevent mosquito breeding.

Control of men and community

(1) *Segregation and Quarantine*.—Isolation and quarantine of gametocyte carriers and segregation of healthy individuals away from the infected, are sound measures but not practicable except in a limited sense. It is, however, possible for newcomers to an endemic area to camp, bivouac or establish living quarters as far from the native communities as possible.

(2) Combating malnutrition is one of the salutary community measures in malaria control. Famine conditions and low resistance caused by malnutrition predispose to malaria by increasing the relapse rate.

(3) *Educational Measures*.—The training in principles and practice of personal and community health right throughout life would develop a basic appreciation of local conditions and problems in regard to the impact of malaria on a community and the scientific and economic way of combating the evil. The second approach is by means of health propaganda. Attempts should be made not to impose on the layman—rather one should aim at developing in the people a desire for those local changes in, or adaptation to environment, that are necessary to prevent diseases like malaria.

(4) *Legal Measures*.—Sufficient legislative provision should be made imposing responsibilities on the people themselves which when discharged will help in keeping down the mosquito population. Health authorities should at the same time be provided with adequate powers to take steps in circumstances which favour propagation of malaria in the community.

(5) *Social and Economic Considerations*.—Measures to control malaria are on the whole costly. The economic level of either the individual family or of the State (both being inter-dependent) has to be sufficiently high for an organised effort to be of any value in the control of this disease. Recent experience shows that killing adult mosquitoes by DDT prove to be the least expensive and yet it may not be within the means of the State or of the community to plan and execute wholesale operations throughout the country.

In a country like India as at present it would be illogical to expect lay organisations for mosquito control to function without frequent and substantial encouragement from the State. Mosquito control, like all human efforts to mould the environment, can be most successfully accomplished when technical skill backed by proper authority, is fired with imagination, courage and enthusiasm. With such attributes we will one day certainly outwit mosquitoes.

In malaria control connected with engineering undertakings of the magnitude of multi-purpose river projects, there are three fundamental essentials which need be stressed from the view-point of administration. Alongside the engineering division, there should be provision for a large and adequate malaria organisation covering the whole area of operation. 'Persistence and not perfection' is the aim and therefore retention of the organisation even after the construction work is over, is imperative. Thirdly, the appreciation of the fact that the engineering and medical

services are each but a department of the vast enterprise and that they should work in harmony with each other so as to ensure fullest co-operation. Without this, little will be accomplished, for many of the projects, be they Health or Engineering, may be spoiled by resistance or resentment if the approach of either is wrong. Results are best obtained only by close co-operation and common understanding of each department's plans and problems.

DISCUSSION

MR. M. B. RAMACHANDRA RAO.—Just twenty years ago I had been working as a Geologist attached to the Soil Survey Parties in the Irwin Canal area connected with the Krishnaraja Sagara Project in Mysore. During that period while the canal was yet being aligned, I could see that there was little malaria in those parts. Of course, in a few of the villages situated close to the tanks, malaria was prevalent; but then the authorities had taken care to get regular malarial surveys carried out. Also, with the collaboration of Engineers and Health Experts—some of whom were connected with the Rockefeller Foundation—co-ordinated plans had been formulated for control of malaria. As far as I understood, the plans were to keep a dry belt around each village site and to rotate wet and dry crops by a Block System of distribution of water in the whole tract. A few years later when I visited the area, the irrigation had brought in prosperity to the people, but the distressing feature was that malaria was raging everywhere. Most of the plans, in so far as malaria control was concerned, must have remained on paper or at least did not appear to have been implemented satisfactorily. The Government were faced with a serious problem. The speaker is therefore inclined to think that drawing up co-ordinated plans are not sufficient and that consideration should also be given to provide effective measures needed to keep certain aspects of the plans from going wrong in actual working.

DR. B. C. DAS GUPTA wound up the discussion on his paper by emphasising the need for proper health surveys in relation to the topography and social features of the population when undertaking multi-purpose river-training projects. He also stressed the need for constant watchfulness and study of the position during and after the execution of the plans.

In the discussion which ensued, Messrs. Kanwar Sain and M. B. Ramachandra Rao and Drs. J. C. Ray, U. C. Ukil and K. L. Rao took part. Drs. A. C. Ukil and J. C. Ray sought for more information on the effect on health of the construction of multi-purpose dams. Dr. K. L. Rao stated that experience, based on survey and control measures, at the Mettur Dam indicated improvement of the health status of the population concerned. Dr. M. B. Ramachandra Rao stressed on the effective enforcement of control measures for success. Mr. Kanwar Sain advocated birth control measures in the control of population for ensuring a hygienic standard of living.

REHABILITATION IN THE DAMODAR VALLEY

*By K. S. V. RAMAN, I.C.S., Director of Rehabilitation and Development,
Damodar Valley Corporation, Hazaribagh.*

(Communicated by Dr. B. C. Guha, F.N.I.)

SUMMARY

Approximately about 60,000 people will be displaced and about 60,000 acres of cultivated land will be submerged when all the projects of the Damodar Valley Corporation scheme are completed. Displacement of people will be by stages as each project matures and the resettlement will keep pace with the construction schedule.

A detailed census has been completed of the population, age groups, literacy data, income of the family in foodgrains and in cash, debts, and the number of bread winners and the nature of main and subsidiary occupations of the people in 79 villages covering 3,970 families that are likely to be affected. The ground plans with detailed specifications of 3,377 houses have been drawn up and an authentic record of rural housing in this area obtained which discloses several points of interest. Type designs for better housing have been evolved using locally available materials, and a beginning has been made with the first village at Bachhai in the Hazaribagh district. Villages are being planned scientifically with necessary forest and pasture. Waste land is being reclaimed on sound principles of soil-conservation. Communal benefits such as electricity, drinking water supply, schools and facilities, will be provided. Steps are being taken to introduce a co-operative way of better living suited to the needs of the people and likely to be acceptable to them.

The Damodar Valley Scheme contemplates construction of eight dams. The reservoirs will submerge about 60,000 acres of cultivated land and displace approximately 60,000 people from their houses. The problem is to find out as far as possible other lands of equal productivity and suitable houses for them to live in. Unlike the case of refugees from Pakistan the displacement here is preplanned and by stages as each reservoir fills. Also, the population is predominantly agricultural. The agricultural and economic well-being of the people of the valley being one of the objectives prescribed for the Damodar Valley Corporation a better way of living has to be planned for the displaced people.

A census has been undertaken of the areas likely to be submerged to get an authentic picture of the life of the people at present in its essentials. Data regarding the population, major and secondary professions, literacy, incomes in foodgrains and cash, debts, number of cattle owned and their provisional option in the matter of compensation, i.e. whether in money or house for house and land for land have been obtained. The ground plan and specification of every house have been drawn up in graph books. The census has been completed so far for 3,970 families living in 3,377 houses in the submerged areas of the Tilaiya, Konar and Maithon reservoirs and in the area required for the Bokaro Thermal Plant. These figures have been shown in the form of village averages in the graphs attached. The figures of income and debt are not as reliable as the rest.

Villages whose houses and lands are likely to be totally submerged are expected to shift out wholly; for this group entirely new villages have to be planned out with lands. Where only a few houses are submerged and a good bit of the land remains free, the people would prefer to stay on and shift the affected houses a little higher up. In such cases attempts are being made to locate suitable waste lands as near as possible and take up what is called island reclamation as distinguished from colonies. For the purpose of planning it is assumed that 70% of the former class would require lands and houses and in the latter case 100% of the land would

be taken. The rest will prefer to take the money in cash and make their own arrangement.

Selection of land for rehabilitation colonies is going on and in the case of Tilaiya, the first reservoir, has been completed. Waste land has to be selected, obviously. Agriculture in this hilly terrain is backward and on account of poor lands, low rents, absence of irrigation and a comparatively large amount of forest, extensive cultivation is the rule. With the result that most of the lands worth cultivating easily have been cultivated and what is left is poor soil or is badly eroded and requires heavy reclamation. The selected land has to be near the original houses. Long shifts are not liked. Certain villages where waste land is available have a bad reputation—possibly that is why waste lands are available there—and are not acceptable. A shift southward is considered inauspicious.

Pending land acquisition quick possession of the land is taken under the Bihar Waste Lands Reclamation Act over a fairly wide area. A detailed soil survey is made and a land-capability map indicating degrees of soil erosion is first drawn up and then a detailed land-use map is made out, fixing the areas to be put under paddy, upland cultivation, ponds and ahars, forests and pasture. The total area of cultivable land being fixed a central high area is selected for the village site and the number of houses is determined by the cultivable area available—the average holding being about 5 acres. Reclamation of land on sound principles of soil and water conservation with its contour terraces and calculated run-offs is being done entirely mechanically. The soils have been analysed and after reclamation the first crop with the necessary manuring—both chemical and green manuring—is grown to bring the lands under proper cultivation. All this work is done by the department of Soil-Conservation of the Corporation.

The village layout is on the contours and adequate road and open spaces are allowed. Houses are put up separately with a bari of 50' × 100'. The majority of the existing houses are separate and enclosed in their own bari. Trees useful and decorative are planted along the roads and as wind breaks. In each bari it is proposed to put in a vegetable tree—Kathal or Sajina and a couple of fruit trees fruiting at different times of the year, e.g., mango, guava—besides a few papayas. All the plants are grown in a central nursery at Hazaribagh. The neighbourhood order of the old village is kept up as far as possible. An adequate number of pucca wells are put in for drinking water supply. And when electricity comes in it is proposed to have an overhead tank and taps near the well and enclosed spaces for bathing and washing. As part of reclamation small ponds are dug out and those near the village should serve for the cattle and fish will be reared in them. A community centre is being provided in each village.

An examination of housing has indicated several points of interest. The plinth area of accommodation per person comes to as high a figure as 140 sq. feet; and 0.6 to 0.7 of a room is available per person. There is certainly plenty of elbow room. The rooms are large having an average area of about 200 sq. ft. The walls are built of puddled earth. As the Sal ballah is the universal rafter the breadth of the room is automatically limited to 10'–15' but the length is considerable. Several small rooms for different purposes do not suit the agriculturist. This high standard is uniformly maintained throughout the areas surveyed as the relevant graphs will show. Windows are few and in the inner walls often a door gap is provided. From a sample survey the area of ventilation in the form of doors, windows, under gaps etc. comes to hardly 5% of the floor area which is a very low figure. The roof is of Sal ballahs with bamboos and naria or country tiles in the areas covered by the Tilaiya and the Konar reservoirs and in Maithon straw takes the place of the tile. The roof is by no means airtight. What is lacking is only cross ventilation. Lighting, however, is poor and some of the inner rooms are dark in the middle of a summer day which is not good. One typical feature throughout is the provision of lofts. Sal ballahs are built into the wall the spacings varying, to form a loft between

5' to 6' high on which is placed most of the articles of the resident. Nearly $\frac{1}{3}$ to $\frac{1}{2}$ the total area of the house is provided with lofts and this proportion has to be provided in our houses.

In planning and building the house the aim has been to put up a house which in its layout will be acceptable to the people, is made of building materials locally available, and constitutes a significant advance in housing so that if it is copied by the neighbouring areas it will raise the standard of housing which is one of the important factors affecting the standard of living. The agriculturist is house proud and unlike the industrial worker maintains a mud house in good condition. The main changes will be, apart from better specifications in buildings, to provide as many windows as will be acceptable to the people from the point of view of privacy and security, niches in walls and shelves to keep things off the floor, a separate kitchen and verandahs with seats in the front and the back. The sizes of existing houses vary from 200 sq. ft. to 3,000 sq. ft. Three types have been drawn up of about seven hundred, nine hundred and a thousand sq. ft. and these will be given to the large majority. A few extra sizes will have to be given to the owners of very large houses but it is proposed to fit in the rest in these types and any adjustment either way in the valuation of the housing and the bari will be adjusted against the land to be given. Type plans of the new houses are attached.

Soil blocks stabilised with cement, cement hollow blocks and pucca bricks were given up as building materials as they proved expensive. Rammed earth building is slow. Temperature variations are from 40° to 110° F. in these areas and more than half the annual rainfall of 50" falls in the three monsoon months and storms with a speed of 50 miles per hour are not uncommon. The final selection has been to build the walls with sundried bricks with 6 layers (3 below and 3 above ground) of pucca bricks with mud mortar at the bottom and 2 layers of pucca bricks with cement mortar at the top of the walls. The outer covering of the earth wall has been a problem. Cement wash, thick and thin, mud plaster, plasters of cowdung mud and cut straw, cement and sand 1:8, and gunnited mixtures of sand and soil, and cement and sand in different proportions have been tried. Some of these have been through a summer and a very wet and early monsoon. The best seems to be gunnited cement in a proportion of 1:6 cement: sand, $\frac{3}{8}$ " thick, and this is being adopted for the rest of the housing. The preliminary costing comes to just under four annas a square foot. The doors and windows are of Sal wood and the rafters also of Sal ballahs. This timber is locally available, but is fairly easily affected by borers and white ants and coal tarring by brush has not proved effective. The question of ASCU treatment is under consideration. Naria tiles are locally made and bamboos are available from forests and they complete the list of building materials used.

The lands and houses form only the basis of a better way of living but the major part of the greater well-being has to come from the people. The main lines on which improvement is necessary are clear. Over 70% are primarily agriculturists; agriculture will remain the main profession and supplementary industries to be introduced must fit in with that. Bamboo, Agave and Sabai grass will be grown in the forests and cottage industries based on these can be developed. As far as agriculture is concerned the main task will be to improve the output and to introduce double cropping. Contour terracing has substantially increased water retention; last winter was particularly dry and a good crop of wheat was harvested on an upland field contour terraced and contour ploughed. Ahar or percolation bands are introduced systematically in reclamation. Minor dams capable of irrigating 100-300 acres are being built where suitable sites offer. Pumped irrigation from the main reservoirs is a possibility when they fill; but the rolling terrain imposes severe limitations and puts the cost of any kind of irrigation. Introduction of green manuring and artificial manure is urgent; this is being done in first cropping newly reclaimed fields and it is encouraging to note that neighbouring cultivators—

after seeing results—are buying small quantities of nitrogenous and phosphatic manures from us. Multiplication of good seeds obtained from the State Government's Department of Agriculture, introduction of a second crop including vegetables, and better agricultural practices will be shown in the demonstration farms located near each colony of rehabilitation and in due course it is hoped to demonstrate better agriculture on farmers' lands with their help. The average size of each reclaimed fields come to over an acre against 0.10 acres in a typical village. A big gain in the initial allotment of such large fields has to be protected from sub-division into fragments. The contour terraces have to be maintained and saved from encroachment.

Including goats and sheep, the cattle population equals the human. The cow here is particularly diminutive and used only for producing equally undersized bullocks and farm-yard manure. It lives on capital by overgrazing the forests and open areas and competes successfully against better grade animals. Artificial insemination accompanied by extensive castration of scrub bulls, development of rotational pasture and protection of forest are necessary. In the Tilaiya area, Bihar State have agreed to start an artificial insemination centre and experiments are being made with new grasses as well as ditch fencing and live fencing with *Agave* and *Inga* dulcies. If these fences are successful, and what is more, the psychology of fenced rotational pasture can be introduced, it would constitute a significant advance in rural economy. Quick fuel producing species are being tried out in the forest. Rural electrification is new to this area and will be tried out.

In the management of land, the co-operative way is obviously the best but is little known and less liked. Joint farming is altogether unknown. Co-operation cannot be forced. The Corporation may have to run communal institutions departmentally and slowly absorb the leading villagers into the management with a view to finally handing over the job to them unless the displaced people agree to co-operative farming or at least co-operative management of institutions other than land from the outset. A scheme is being worked out for the Tilaiya colonies and will be put to them.

ECONOMIC SIGNIFICANCE OF THE MULTI-PURPOSE APPROACH

By S. N. MOZUMDAR, I.C.S., Chairman, Damodar Valley Corporation

The symposium has brought together a wealth of thought on the various aspects of multi-purpose river development projects. I shall confine myself to a few broad remarks, bearing on the more important economic implications of the multi-purpose approach.

Not long ago dam projects were almost completely single-purpose. Where the same project served more than one purpose, this usually happened more by chance than by conscious design. In recent years three things have combined to push the concept of multi-purpose project to the forefront: A new resource—consciousness among the Government and the public, as a result of which the need for getting the utmost from water and other resources is becoming increasingly clear; progress in engineering and allied sciences, which has revolutionised the technique of dam construction; and the practical demonstration given by the TVA of how much can be achieved for increasing wealth and welfare through a comprehensive systematic application of the multi-purpose approach to an entire river basin.

The fundamentals of a sound water policy were perhaps best set forth in the U.S.A. by the Water Committee of the National Resources Committee during President Roosevelt's Government. These fundamentals would bear repetition in as much as they touch the very core of a rational water policy, whether in the U.S.A. or elsewhere.

1. Water control is not an end in itself but only a means for the promotion of social welfare. Without a conscious pursuit of this goal no expenditure to control the behaviour of water would be justified.

2. Wherever feasible, progress must be through multi-purpose projects. That is to say, every project must be so planned and constructed as to yield every possible benefit. Not to promote the maximum integrated control and use of water is 'to invite waste of potential wealth and so is incompatible with the public interest'.

3. The entire drainage basin of a river system should, as a rule, be treated as the unit area of operation. For 'a chain of connected problems extends from the source of each tributary to the mouth of the main river.' It follows that the optimum overall results can be achieved only through a well-integrated programme comprising all the problems of an entire drainage basin.

4. Co-operation between the Federal Centre and the States is essential in the management both of *intrastate* and *interstate streams*. 'Many States have appeared to be highly, and properly, sensitive to their rights, but correspondingly insensitive to their responsibilities; it must, however, be clearly recognised that 'eventually authority over streams necessarily goes hand in hand with responsibility for them.'

5. Study of facts must be regarded as an essential pre-requisite to sound action. Plans for the development of large river systems must be invariably based on a most careful study of adequate data covering every aspect of the problems involved, and never on mere opinions, no matter how widely held.

6. In judging the economic soundness of projects not only specific, but also all general and potential benefits must be taken into consideration. 'Social accounting should take its place with economic accounting.'

These principles found their first wide application in the Tennessee Valley. The results of this are known to us all, at least in their broad contours. A few years ago, Lilienthal gave us a vivid account about what he called the people's dividend from the Federal investments in the TVA. The figures then given by him would,

of course, need some adjustments now. But his main conclusions would hold good today at least equally, if not with greater force. According to the estimate given by Lilienthal the surplus revenue from power would be enough to repay the entire capital within 30 years, so that by 1974, the whole capital would be fully paid back and yet assets valued at \$450 millions would be left intact since depreciation is currently charged against rate-payers while the Federal exchequer would continue to receive a large income from this 'paid-out' investment. Even if a 2 per cent interest were charged on the capital invested for power development, the entire capital could be retired in 60 years after making adequate provision for maintenance and replacement of property. If the interest charged were $2\frac{1}{2}$ per cent, the same position would be reached in 80 years. Lastly, if the entire investment for power, navigation and flood control were charged exclusively against power, even then the capital could be retired in less than 60 years with the revenues from electricity.

There are, of course, other gains which should enter on the credit side of TVA's balance-sheet. The Tennessee, which was not long ago an annual threat, is now the best controlled river in the world. Huge annual losses have thus been avoided. Traffic moved on the river has increased by leaps and bounds. Fish cultivation has received a great stimulus. The liberal provision of recreational facilities is attracting a stream of visitors every year. On the agricultural side, the greatest achievement has been the control of soil erosion. Large areas of badly eroded land have been revitalised. Output of small grains has increased appreciably; the volume of corn output has remained constant, but, owing to the higher acre-yield, it now takes up a much smaller area; production of hay has increased by 33 per cent. On the demonstration farms, as a result of the new farming method, the rate of increase is three times higher. Under new farming the same acreage with the same manpower now produces 30 to 60 per cent more meat, eggs, milk and dairy products. In addition, the grazing season is now longer, the grass is more nutritious, the corn grown has improved in quality and the same acreage now supports more animals. The supply of cheap and abundant electricity has resulted in the rapid growth of a host of industries in the region ranging from food, fibres, timber products, metals, chemicals, to the large-scale production, especially since the outbreak of the last war, of aeroplanes, explosives, incendiary bombs, etc. As a result of this all-round development the per capita income in the valley has risen by a higher margin than in the country as a whole.

The TVA approach has been frankly applied to the Damodar Valley. The Damodar Scheme has been drawn up so as to cover the entire river system from its source to its mouth and to extract the utmost possible benefit out of its water resources. The main features of this scheme are well-known to you, as also the major benefits expected out of it. You also know that Mr. Voorduin estimated the cost of the Damodar Scheme at Rs. 55 crores. Incidentally, his tentative analysis showed that the three major benefits—flood control, irrigation and power, as envisaged in the Scheme—would have called for 50 per cent more capital outlay, if they were to be covered through single-purpose structures. This, in other words, is the measure of the saving in capital cost directly resulting from the application of the multi-purpose approach.

What will be the ultimate cost of the Damodar project? The question has been raised over and over again during the last few years. It is only natural that the Government and the public would like to know how much money is involved in the project. We too would indeed like to know the figure! But can we? As scientists, you would know better than myself what difficulties are involved in giving a firm cost estimate for a multi-purpose project covering eight dams, ten hydroelectric stations, a large steam power station, one irrigation barrage, about 1,500 miles of irrigation canals and distributaries and about 600 route miles of transmission lines, the completion of which will necessarily run into several years. Broadly speaking, four factors impinge on the question of cost.

1. Designs and estimates of quantities;
2. Method of construction;
3. The element of time; and
4. Price movements at home and abroad.

Firm designs and estimates of quantities are, of course, the basis of dependable estimates of project costs. A good deal of surveys, investigations including foundation exploration and planning must, however, be carried out before actual design work can be undertaken. The production of drawings itself is a laborious and time-consuming task. Only after designs have been finalised, the quantities involved can be estimated. Even then no designs and estimates of quantities can be one hundred per cent firm. They may and do vary as construction goes on. Above all, foundations may throw up last-minute surprises affecting quantities and cost.

The scope for mechanised construction work has considerably widened in the country as a result of the rise in prices and wages since pre-war days. How far the mechanised method can be adopted even when it promises to be economical will however depend on the availability of the necessary equipment and of the technical personnel for operating the equipment including its repair and maintenance and also for training up Indian personnel.

The importance of the time factor has not always received the emphasis it deserves in this context. In the case of the DVC the bearing of time on cost is all the more important because we are charged $3\frac{1}{2}$ per cent interest per annum on the money from the day it is advanced to us. It is well-known that overheads in a construction organisation are heavy. Unless an attempt is made to carry out the project at a reasonable pace overheads and interest charges will pile up and add on to the cost. Yet, we are unfortunately not in a position to draw up and adhere to a firm construction schedule because, apart from other things, we do not know where we stand with our funds. The time-table may be and, as a matter of fact, has been, upset owing to unforeseen fluctuations in the flow of funds.

Prices, both at home and abroad, are in a state of flux. Last year for a little while, world prices showed a downward tendency. The dip did not, however, last long. In India, the devaluation gave a fresh spur to prices of key commodities. Today owing to the war scare inflationary forces seem to be gathering new momentum. In normal conditions it should take six to seven years to complete the Damodar project. But who can hazard a forecast about the behaviour of internal and external prices over this period? I certainly do not claim any such prophetic qualification.

Let us again look at the TVA. In 17 years it has built about 20 dams. Some more are under construction. Others are being planned. During these 17 years prices have climbed from the low level of the depression years to a record peak. What would have happened to the TVA if, before undertaking construction, it were required to come up with a complete estimate of cost for the entire project? The answer is not far to seek. An insistence on meticulous cost estimates would have held up progress indefinitely and the country would have been nowhere near reaping the benefits which we have outlined before.

Does this mean that we have no other choice than to take a financial leap in the dark? Luckily, the position is not that bad. All that I am suggesting is that our approach to the question of cost estimates, as related to basin-wide development schemes like the Damodar Scheme, must be less rigid and conventional because of the complexities inherent in the problem itself. To ask for firm estimates of cost for the entire scheme is, in such a case, to ask practically for the impossible. We can, however, ask for, but must also be satisfied with, reasonable forecasts both of ultimate costs and financial results. In other words, we must carry out essential preliminary surveys and investigations; draw up project plans based on the best possible engineering judgment about cost; prepare both financial and economic analysis of the project including a general assessment of its revenue-earning and

wealth-creating potentialities; and if the analysis shows that the project deserves high priority in the nation's overall programme of development, go ahead with its execution, but exercise at every step the utmost vigilance so as to carry it through at minimum cost and within optimum time.

This is exactly what has happened in the case of the Damodar Scheme. Mr. Voorduin's estimates of Rs.55 crores was frankly based partly on engineering facts and partly on engineering judgment, as is inevitable in such cases. There is little doubt today that if this figure happens to be out by a substantial margin, this would be due primarily to the movement of prices. Supposing inflationary forces boost up prices in India and abroad, what would happen to the economics of the Project? Let me hasten to add that rise in cost due to a general rise in prices is most unlikely to have an adverse effect on the economic soundness of the Scheme. For, if prices go up, so will the money value of the 200,000 tons of extra food, 700,000,000 kwh, of energy, the flood damages prevented by the Project and various other ancillary benefits which the Damodar Scheme will yield. In fact, given a general rise in prices the economic balance-sheet may even improve rather than worsen. For example, this will be the case if food prices rise, as may well be, by a wider margin than other prices.

Meanwhile, there are several reasons which should reassure us about the people's dividend from the public investment in the Damodar Scheme:—

1. Though the number of dams is large—eight in all—they are small and medium-sized. In fact all the eight dams taken together do not even add up to some of the bigger dam projects now before the country. The individual dams in the Damodar Valley can be completed within a comparatively short time. As each dam is finished, it will begin to yield the benefits. The waiting period between investing the money and realising the benefits will, therefore, be short.
2. There is a ready market for power in the Valley and its neighbourhood. In fact, the problem is how soon we can produce power to meet the existing demand. There is also a canal system already in existence in the Lower Valley which could use the water from Tilaiya and Konar as soon as they are ready. Because of this the lag between the completion of a dam and the productive utilisation of the water will be almost nil.
3. The Damodar is a small river, but it has a high capacity for flood damage, because of the capital already invested in the area, the high quality of agricultural land, main arteries of rail and road communication running through the valley and the proximity to the Port of Calcutta. Damages caused by Damodar floods in the past are among the highest on record in this country. It follows that the money value of the flood control benefit will be correspondingly high.
4. The seasonal hydro can be more easily firmed up with steam power in this coal valley than almost anywhere else in India. This will make it possible to tap fully the large proportion of seasonal water power.
5. The Lower Damodar Valley consists of fertile alluvial soil which is capable of a far higher level of agricultural activity. At present the vagaries of the monsoon frequently damage the rain-fed paddy crop grown over most of the area, while the land lies idle during the dry weather for want of irrigation. More crops and larger output per acre could go a long way to meet the growing food shortage in Calcutta and West Bengal.
6. The traffic density between Calcutta and the valley is among the highest in India. Water transport and railroad electrification would be both welcome and economically justified.

7. The mineral wealth of India is largely concentrated in the Damodar Valley with the result that its industrial potential is unusually high. Since coal and iron and steel are the basis of industrial progress, what happens to the Damodar Valley area will continue to determine largely the future pace of our industrial progress.
8. To this should be added other benefits like assured supply of water for industrial and domestic use in the Valley where many localities suffer from an acute shortage of water for several months in the year, large possibilities for fish culture, control of malaria especially in the Lower Valley and recreational facilities around the lakes, which will be available to the mining and industrial population.

Should we defer these benefits in an attempt to prepare meticulously correct cost estimate, when we know that even the most carefully prepared estimates based on firm designs and quantities could be largely vitiated by price movements and other factors? To put the question is, I believe, to answer it.

Before concluding may I invite your attention to three elementary facts about our economic life:

1. India is an old country with a large population which is growing at the rate of almost 1 per cent per year. Large as are our natural resources, their ratio to our population is small. We must, therefore, use our resources with the utmost care so as to get the maximum wealth out of them.
2. Our rainfall is largely concentrated in three months of the year. This means that, unless we are able to store the water to a very large extent and spread it over the whole year, the land will continue to go dry after the monsoon and will refuse to grow the food we sorely need for this large and growing population.
3. Our coal is concentrated overwhelmingly in one single pocket of this vast country. In most parts of the country we must, therefore, get our power from water and not from coal for the simple reason that it is too far away.

If we put together these three simple facts, multi-purpose river development for flood control, irrigation, power and water transport becomes the first axiom of our economic life. Such development, if accompanied by every effort to salvage every possible benefit, holds out the best possible hope to attain a reasonable living standard for our people.

DISCUSSION

DR. K. L. RAO.—The author is to be congratulated on the excellent and clear cut exposition of economics of Damodar Valley Project. Everyone should agree with the principle that if a scheme is proved to be beneficial and productive of great gains, the sole aim must be to bring to fruition the scheme.

I would like to point out the great prosperity that the nation would derive by developing Krishna and Godavari river projects. These rivers carry annually 44 and 82 million acre-ft. compared with 10 million acre-ft. of Damodar. There are excellent dam sites on Krishna and Godavari and vast uncultivated lands that can be brought into cultivation. Any scheme on these rivers would prove immediately beneficial even during construction by enabling development of second crop in the existing deltas at tail end. It is a great pity that even to-day, these rivers of wealth are left out and allowed to go wastefully into the sea.

Mr. Mozumdar stated that the dams to be built in Damodar Valley are not difficult structures. If that be the case, I will earnestly request and plead with the author, who happens to be the Chairman of the D.V.C. Board, that the design and construction of these dams may be entrusted to Indian Engineers. This would prove economical and help in the advancement of Engineering in this country. One of the great achievements of the T.V.A. was that it provided great chances for the American Engineers to develop advanced and economical methods of design and construction.

SRI KANWAR SAIN —Mr. S. N. Mozumdar has done a service in bringing to the fore-front the fundamentals of a sound water policy as enunciated by the Water Committee of the National Resources Committee during President Roosevelt's Government. It is essential that waste of potential of any river basin must be avoided by complete co-operation between the Central Government and the States which are concerned in a particular inter-state stream.

2. While I agree with Mr. Mozumdar that it is difficult to get absolutely correct ultimate figures of cost of the Damodar Valley Project, I consider it necessary that a fair project estimate should be prepared so far as that can be seen at present. The T.V.A. prepared estimates for all of their projects as they carried on. Of course, it may not be possible to get an estimate for every work which is not foreseen at present. The financial picture has, however, to be satisfactory. It is not necessary that if a project is carried out at a time when cost is high, the return will also be better. The expenditure, as has happened in the past on some project, might have been incurred at a time when the prices were high and after the completion of the project came the slump when prices of all products from the project went considerably down. On the other hand some projects have been more lucky. They were constructed at a time of slump of prices but when they were completed the food prices went high and these projects paid a very handsome returns. Unfortunately, in river basin projects which take a number of years for completion and quite a number of years for development a correct forecast is not always easy. The framers of the project have to satisfy themselves taking a very long range view.

In the case of projects which can be divided into several phases it would be desirable to study the economic and financial aspects of each phase of the project so that phasing can be done with a view to obtain the optimum financial results.

I agree with the author that multi-purpose river projects should have very high priority in order to attain a reasonable living standard for our people.

In bringing the symposium to a close, Dr. W. D. West, on behalf of the Organising Committee and of the National Institute of Sciences of India, thanked all those who had attended the meeting and made valuable contributions to the subject.

The major multi-purpose projects that were being planned were likely to give a great impetus to the development of India. They had caught the imagination of the people, and they should be pushed through with courage and determination.

APPENDIX

An extract from Sardar Vallabhbhai Patel's address delivered to the Central Board of Irrigation at New Delhi, on October 24, 1950.

'My own study of the outline of many schemes that I have interested myself in and the results of my discussions with the many engineers with whom I have had the privilege of coming into contact have convinced me that, if the need for circumspection and economy, a due regard for the essential and inescapable conditions of work and problems with which we are confronted and the application of scientific imagination to the facts which stare us in the face rule the surveys, the preparation of plans and estimates and the execution of many an engineering scheme it would not only facilitate the scrutiny of a scheme in its proper perspective, but also enable us to do much more within available resources than is being done at present. In our desire for quick results or for self-glorification, we are apt to launch on ill-considered scheme or big enterprises without adequate reflection and thereby perpetrate a criminal waste of the nation's hard-earned money. I would beg of you, Members of the Board, not only to keep in view this vital aspect in your deliberations and researches but also to influence, by your exertions as well as by your example, your colleagues working elsewhere to live up to this inexorable demand of science as well as patriotism.

There is also another feature of these River Valley Projects which has struck me as deserving of every serious consideration. My own view is for whatever it may be worth that a greater attention needs to be paid to scientific planning of crops and industrial enterprises in the areas commanded by these projects. In the many schemes that have come to my notice I have found little evidence of such planning. There are vague and general references to the crops that could grow and electrical energy that would be produced, but there is very little detailed attention paid to planned processes of agricultural and industrial economy in these areas. Mere availability of canal waters or production of electrical energy is not going to solve the problem of a River Valley Project. The planners must have a clear picture of the crops that should be grown, the lay-out of the fields and villages and the needs of villagers who would grow those crops as also of the industries which would actually be set up and the lay-out and plans of industrial undertakings and towns which would grow. Unless we have this overall planning in advance we cannot utilise to the maximum benefit the waters which would flow or the electrical energy that would be produced. From a wider point of view also, such a planning would be eminently desirable. Centuries of habits or a particular style of living have made us take things for granted. It is in these regions—veritable new colonies—that we can strike out new paths and explore fresh fields. We can shake off the dead-weight of custom and evolve new ways and methods of living and occupation which can go to solve some of the economic problems which affect our very existence.'

